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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JULY 2023

CUBESATS
Transforming Space Science

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A LOOK BACK AT WHAT WE INTRODUCED DURING A PANDEMIC

A lot of things got interrupted while we were all wearing masks and avoiding social situations. But one thing that persisted was Sky-Watcher's commitment to quality and innovation. In case you missed it, here are a few of the things that launched while we were all at home binging Netflix and waiting for our sourdough to rise:

CQ350 Pro Observatory-Class Mount. This 77-pound payload, all-metal construction mount features dual belt drives and an integrated cable management system.

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Now that you know what you may have been missing, go to your preferred authorized Sky-Watcher dealer or visit skywatcherusa.com for more details.

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And let's not forget the What's Up? Webcast. That was our attempt to stay in touch with everyone while we weren't going to trade shows and star parties. We think that turned out pretty well.

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The image on the right is the famous Pillars of Creation (M16) taken with the Wide Field Planetary Camera of the Hubble Space Telescope. The image on the left is taken with a QHY600M-PH Camera through a 7-inch refractor from the author's backyard in Buenos Aires. Courtesy Ignacio Diaz Bobillo. To see the original composition, resolution and acquisition details, visit the author's Astrobin gallery at https://www.astrobin.com/users/ignacio_db/

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A CubeSat deploys from the International Space Station.

SAMANTHA CRISTOFORETTI / JSC / NASA

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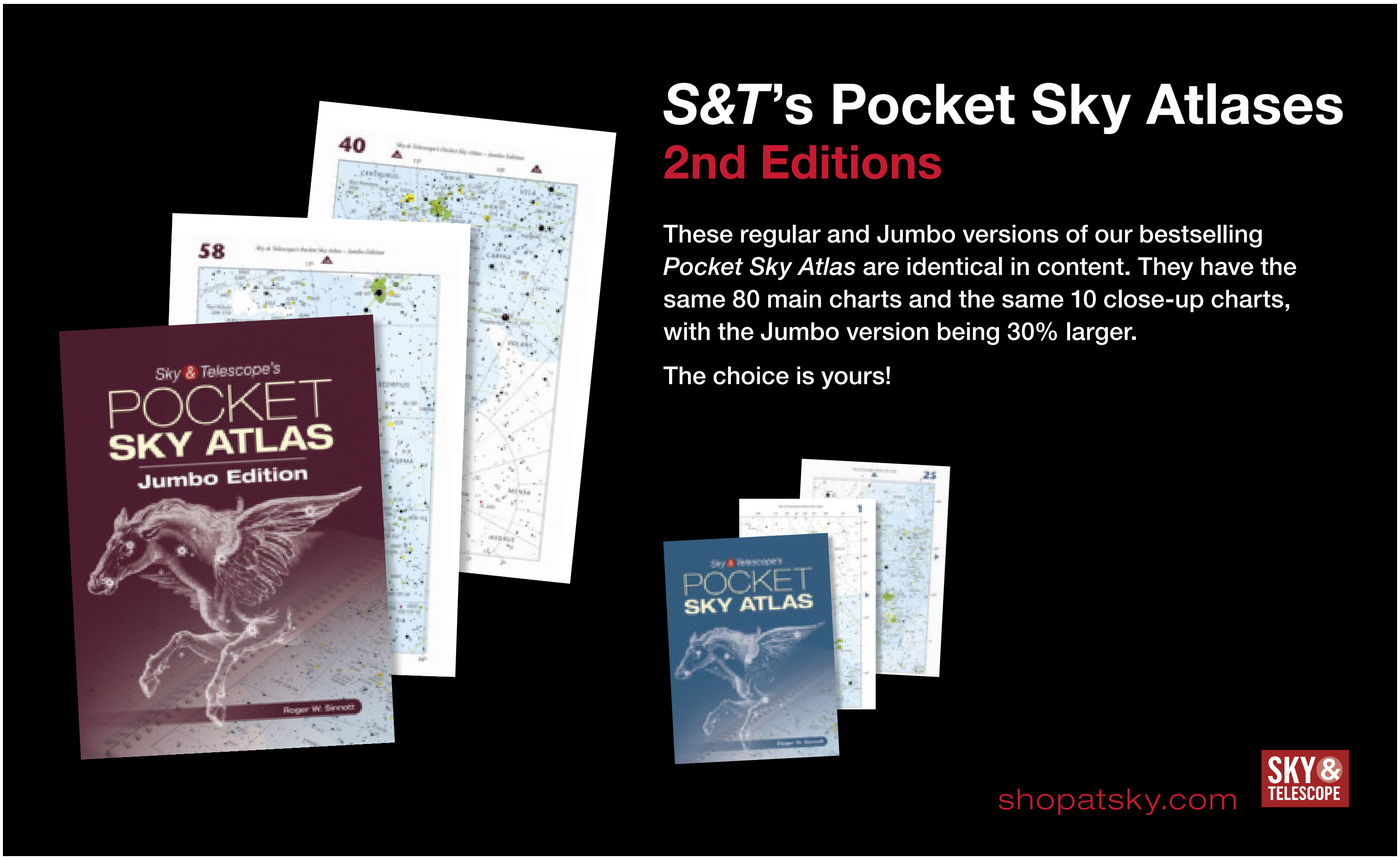
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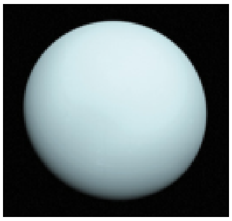
The Case for Uranus

LOOK AT THE IMAGE BELOW. It's a view of Uranus that Voyager 2, the only spacecraft we've ever sent near the seventh planet, beamed back to us in 1986. The pale-turquoise orb looks beautiful but bland, just a featureless marble with little to draw the eye.

Now look at the Hubble telescope image that opens our Uranus feature on page 14. Bland? Featureless? Hardly. Taken only a dozen years after Voyager 2's flyby, in 1998, this false-color infrared portrait reveals at a glance how mistaken that impression of dullness is. (For equally eye-opening Webb telescope images of Uranus and its moons, see **https://is.gd/WebbUranus**.)

Voyager 2 passed the planet during Uranus's solstice, when continuous sunlight on the southern hemisphere triggered the formation of a methane haze that obscured everything. But as the Hubble picture shows, even halfway to the next equinox Uranus's atmosphere displayed loads more character than seen in the Voyager 2 shot.



▲ Mysterious world: Uranus captured by Voyager 2 in 1986

NASA / JPL-CALTECH

In the image on page 14, green and blue regions indicate where the Uranian skies are relatively clear and sunlight penetrates deep into the atmosphere, while yellow and gray areas capture where solar rays reflect off higher haze or cloud layers. Orange and red colors denote high-altitude clouds, some racing along at more than 500 kilometers per hour (300 mph).

But these features are almost ho-hum compared to others that Uranus boasts. As seen in the Hubble image, which shows the planet in its proper orientation to the ecliptic plane, Uranus lies on its side. Unlike all the other planets, it rotates at a nearly 90° angle from the plane of its orbit, rolling like a cylinder rather than spinning like a top.

This odd tilt generates the most extreme seasons in the solar system: In Uranus's 84-year orbit of the Sun, its summer and winter each last roughly 21 years. Day and night as we know them only occur in the planet's spring and fall, when they cycle every 17 hours.

There are more quirks, which Emily Lakdawalla explores in her feature. As she passionately argues, these idiosyncrasies combine to make a compelling case for sending a major mission to Uranus. She's not alone in this wish: Planetary scientists are calling for a flagship mission, akin ideally to the Cassini mission to Saturn, that will boldly go where we've gone only once before.

The Kepler mission revealed that a majority of exoplanets may be *ice giants* between a few times Earth's mass and roughly that of Uranus or Neptune. To have any hope of understanding those extrasolar ice giants, let alone our own, we need to send a flagship mission to Uranus. Your move, NASA.

Peter

Editor in Chief

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The Essential Guide to Astronomy

Founded in 1941 by Charles A. Federer, Jr. and Helen Spence Federer

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Subscription Rates:
U.S. and possessions: $57.73 per year (12 issues)
Canada: $73.18 (including GST)
All other countries: $88.63, by expedited delivery
All prices are in U.S. dollars.

Customer Service: Magazine customer service and change-of-address notices: skyandtelescope@omeda.com
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NEW
Less Can Be More !
Strain Wave Drive Mounts
This year is shaping up to be iOptron's most innovative yet! In 2022 we stepped on to the strain wave drive stage by introducing the highly anticipated HEM27 and HEM27EC. These two models provided a window into the freedom found through a drive system that doesn't rely on a balanced payload to function. With no cumbersome counter-weights or shafts, these mounts ushered in a new level of portability. This year iOptron will be expanding our strain wave driven products into 3 groups of mounts.
HEM: Consisting of three payload capacities - 15lb, 27lb, and 44lb - HEM versions are available as standard or with EC precision encoders.
HAZ: A new GoTo alt-az mount design utilizing strain wave drive technology on both axes. Two models, one with a 31lb the other a 46lb payload capacity, each featuring our easy set-up "level and go" system. Perfect for satellite tracking, supporting binoculars, or visual observing.
HAE: Offering both equatorial and alt-az modes, this dual-axis strain wave drive mount can do it all. The HAE will be available as a 29lb or 43lb payload capacity model, with or without optional EC (precision encoder).
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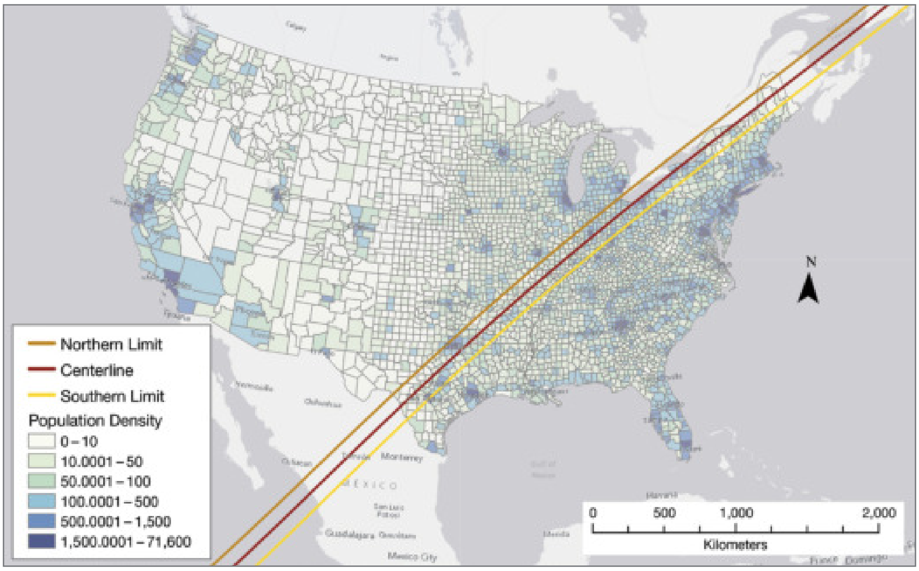

▲ This map compares the population density of the United States with the path of the total solar eclipse in 2024.

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An Eclipse for the People

Hurrah for Fred Espenak and Jay Anderson's "Get Ready for Totality in '24" (*S&T:* Apr. 2023, p. 26). Right away they get into what makes next year's total eclipse of the Sun different from all others: the number of Americans poised to see it with their own eyes. Many people will not have to travel at all. It's almost as if this total eclipse "conspired" to maximize the number of cities and high-population areas along its path.

Thomas Hockey
University of Northern Iowa
Cedar Falls, Iowa

Thank you for running the detailed and useful story about the 2024 solar eclipse, which will be of great use to readers traveling to the path of totality. For those of us who work in astronomy education, the eclipse represents a remarkable opportunity and challenge for public outreach. Some 500 million people could see at least a partial eclipse and will need reliable and safe viewing instructions.

A group of us have proposed and obtained a grant from the Moore Foundation to distribute 5 million eclipse glasses and information booklets through 10,000 public libraries nationwide. Long before the day of the 2024 eclipse (and the annular eclipse this October), these libraries will want to offer public programs and "Sun parties." We hope that the many eclipse enthusiasts among *S&T*'s readers will volunteer to help their local library by calling them or registering at: **https://is.gd/eclipsevolunteer**. The project is coordinated by the Space Science Institute in Boulder.

Andrew Fraknoi
Fromm Institute, University of San Francisco
San Francisco, California

The Naked-Eye Cluster Quest

Fred Schaaf's excellent February Evenings with the Stars column "A Naked-Eye Cluster Quest" (*S&T:* Feb. 2023, p. 45) challenges readers to spot winter's more prominent open clusters unaided. I made several attempts on this winter's rather rare clear evenings with my mid-60s eyes. The results, from near the Illinois-Wisconsin border at 42.5° north, were mixed. M44 was visible every try, validating Schaaf's practical definition of suburban skies, and both M35 and M41 popped out on occasion. But the Auriga trio and multiple targets in Perseus were always bridges too far.

One very transparent February evening, I noticed 2nd-magnitude Zeta Puppis culminating and deployed 15×63 binoculars downward along the 8-hour arc of right ascension from the star's roughly −40° declination. A bit to the left of straight down, just above the horizon, I spied a reddish glow that moved westward with time. It was Gamma Velorum!

At −47.2° declination, even allowing for atmospheric refraction, it was certainly near the limit of visibility from my latitude. I confirmed the observation the following evening and two more times in mid-March.

Two interesting things about objects at the limits of one's southern horizon are the dramatic effects of atmospheric extinction and Earth's rotation. Gamma Velorum is a bright (around magnitude 1.8), multiple-star system with dominant O-class and Wolf-Rayet components. Yet a half degree from the horizon, the system appears to be a red ocher color. And being so far south, this distant object skims rapidly above the foreground because it subtends such a shallow arc from 42.5° north.

Schaaf's columns motivate me and many others to get out at night and explore the sky. And one never knows what personal discoveries await. Keep up the good work!

Ed Furlong
Walworth, Wisconsin

An Island to Call Home

I was amused to see our North Island of New Zealand beautifully displayed on the cover of the March issue, looking so crystal clear. I should remind you that our indigenous Māori society here calls New Zealand Aotearoa, The Land of the Long White Cloud. Despite that description of our astronomical skies, we really do have several thriving professional and amateur observatories.

Michael Snowden
Christchurch, New Zealand

Unknown Flying Object Identified

I enjoyed reading David Grinspoon's "ET on Earth?" (*S&T:* May 2023, p. 12) on the effort to determine how common extraterrestrials really are. I noted

a photo from a video of a Navy aircraft encounter in 2015 was included. I used to work on those infrared cameras, and that UFO is simply a little bug inside the camera that's out of focus! If you look at several similar videos, you can almost make out the bug's antennae and legs. The bug turns around, then flies away. I guess it is a real UFO, because I can't identify what species of insect it is.

Don Bruns
San Diego, California

Proplyd Problems

When I first read Dave Tosteson's Going Deep article "The Newborn Nursery of Orion" (*S&T:* Feb. 2021, p. 57), I felt overwhelmed considering his observations were made with a 32-inch reflector, and I hadn't even looked through a larger telescope than my 10-inch Schmidt-Cassegrain. This past winter, though, I attempted the unthinkable. I tried to see the brightest proplyds he wrote about in my recently acquired 16-inch Dobsonian.

To my great surprise, I was able to see two: 159-350 and 106-417. And on a perfect night, I was even able to glimpse 159-350 in my old 10-inch Schmidt-Cassegrain! This got me to reading a lot of papers on the brightest proplyds, and through this I realized that the correct designation for the one he called 106-417 is in fact 244-440 (**https://is.gd/DeuteriumOrionNebula**). However, the mistake wasn't Tosteson's alone considering how I then found a 2009 NASA/ESA press release image (**https://is.gd/HubbleProplydHighlights**) that had made the same exact mistake! I've since contacted them, and they made an "Editor's note" based on my findings.

Scott Harrington
Evening Shade, Arizona

Enchanting Skies

I was watching a PBS telecast of an Andrea Bocelli concert a while back when a guest singer appeared on stage, and it was announced his song would be "Home on the Range."

I thought it odd for such a venue and didn't pay much attention, until I noticed the lyrics of the fourth stanza. I was blown away.

How often at night, when the heavens are bright,
With the light from the glittering stars,
Have I stood there amazed, and asked as I gazed,
If their glory exceeds that of ours?

It pretty much sums up why so many of us, when standing in a field on a dark night, are enchanted with astronomy.

Bob Spaulding
Edmonds, Washington

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75, 50 & 25 YEARS AGO by Roger W. Sinnott

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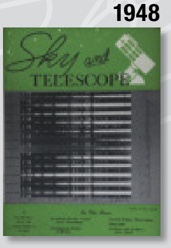

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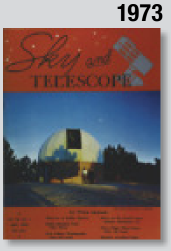


1998

July 1948

Stellar Atmospheres "Another eclipse of Zeta Aurigae has come and gone. [During the day on January 21st] the emergence from total eclipse began, and for the next several days the spectrum went through remarkable changes as the small star [probed] the gaseous envelope that surrounds its giant companion. . . .

"In a general way, the arrangement of the atmospheric strata in Zeta Aurigae is similar to that of the sun's atmosphere, but on a vastly expanded scale. Metals in the neutral state, such as iron, manganese, and titanium, occupy the lowest layers. Higher up we find no neutral metals except magnesium; instead there are many ionized atoms of metals, especially titanium . . . The highest layers show only hydrogen and ionized calcium, which extend above the giant star's surface to a distance equal to about half its radius."

Describing his bounty of new findings, University of Michigan astronomer Dean McLaughlin lamented that the work could easily have been done decades earlier.

July 1973

Solar Flares "The strongest radio signals received on Earth from astronomical objects are generated by solar flares. They are . . . about 10^5 times stronger than the [signals] received from the Crab nebula . . .

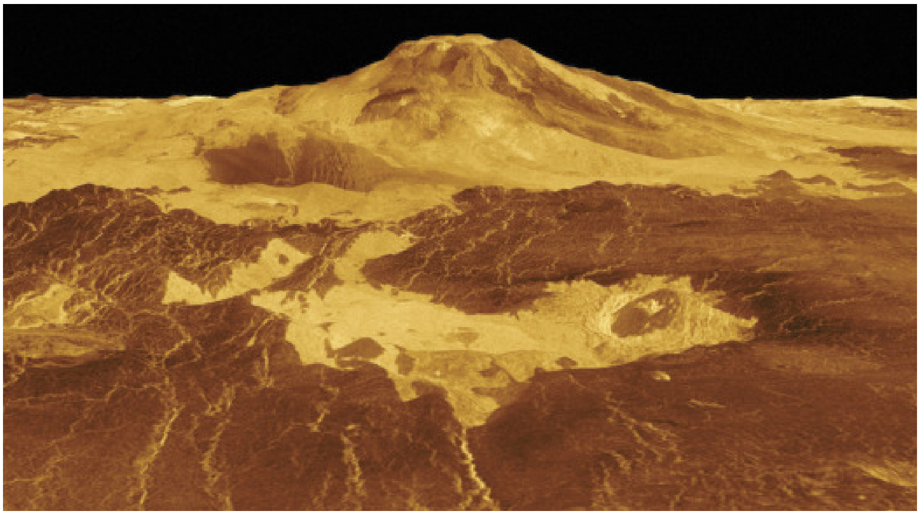
"In their analysis of data from the great solar flare of August 7, 1972, [NASA scientists tracked its shock wave in detail]. The shock traveled at an average speed of 1,270 kilometers per second, a value that remained nearly constant from the flare region out to the earth, and its arrival at the earth coincided with the sudden commencement of a geomagnetic storm. This remarkable result gives a striking confirmation of the long-held theory that a terrestrial magnetic storm is initiated by a shock wave which is generated by a solar flare . . ."

July 1998

Aldebaran's Planet "A handful of middle-aged, Sun-like stars seem to have planets of some kind orbiting them. The evidence: those stars move toward and away from our solar system with clocklike regularity. More precisely, their glowing photospheres do so. [But] rapid rotation, magnetic activity, and pulsations all seemed equally likely causes for the cyclic variations.

"Now, however, exacting observations have made it a bit more likely that one nearby giant star harbors a giant planet. Aldebaran (α Tauri) evinces a mildly eccentric (e = 0.18) motion with a 650-day period. If orbital in origin, this suggests a planet or brown dwarf with at least 11 times the mass of Jupiter. [So says a] pioneering 1995 study led by Gordon A. H. Walker (University of British Columbia) . . ."

In 2015, using 30 years of observations, German astronomer A. P. Hatzes and colleagues confirmed that Aldebaran both pulsates naturally and has such a planet.



▲ This computer-generated 3D model of Venus's surface shows the summit of Maat Mons.

SOLAR SYSTEM

Finally! Scientists Find Active Volcano on Venus

FOR DECADES, scientists have both suspected the existence of and searched for active volcanoes on Venus. Its surface is geologically young, perhaps only tens of millions of years old, meaning that lava flowed recently on our sister planet. Now, a new analysis of three-decade-old radar images from NASA's Magellan orbiter has resulted in a definitive detection: In 1991, there was volcanic activity on the surface.

"We've never had evidence as strong as this," says Paul Byrne (Washington University in St. Louis), who was not involved with the study.

Magellan orbited Venus from 1990 until 1994, when it plunged into the hellish atmosphere. But before the mission's end, the spacecraft's synthetic aperture radar mapped almost all of the Venusian surface, showing features as small as 120 meters (390 feet) across.

These maps were sent back to Earth and stored digitally on CDs. It took years for in-depth probing of the surface to become possible. "You need to be able to load in a few hundred–gigabyte data sets, pan around on the surface, and zoom in and out," says Robert Herrick (University of Alaska Fairbanks). Herrick presented the study on March 15th in *Science* and at the 54th Lunar and Planetary Science Conference in Woodlands, Texas.

Herrick searched the data the old-fashioned way — by eye. "There's no automatic algorithm that will allow you to search for those changes," notes team member Scott Hensley (Jet Propulsion Laboratory). Computers have gotten quite good at pattern recognition, but spotting differences in Magellan images requires taking into account the different viewing angles of each image.

Since his search was manual, Herrick narrowed his scope to the most likely volcanic areas. He'd pored through only 1.5% of the planet's area when he hit paydirt. On Maat Mons, which is itself a volcano, Herrick spotted a caldera that had enlarged over an eight-month period, changing from circular to kidney bean-shaped. The caldera also became shallower and its floor darkened, possibly indicating it had filled with lava.

To verify that the detection wasn't a trick of the light, so to speak, Herrick and Hensley used Magellan's topography map to correct their radar images so that they both appear as if viewed from straight above, a process called *orthorectification*. They conclude that the caldera's changes in size, shape, and brightness are real.

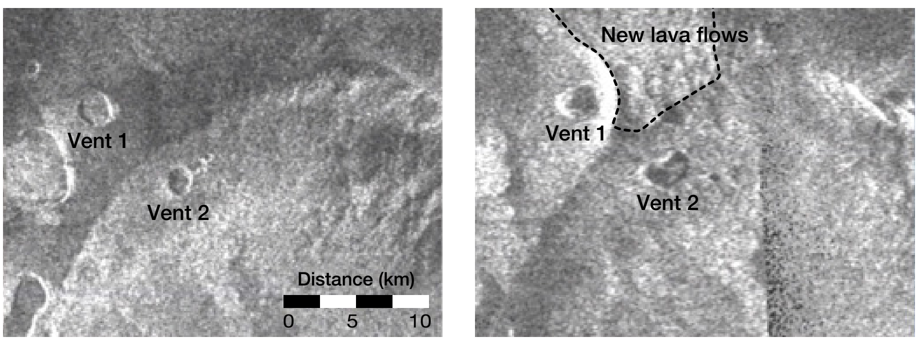
One scenario is that the first radar image caught the caldera in between eruptions. "If the magma chamber is still down there and still getting fed every now and again, you might get a later eruption in the exact same place," Herrick explains. Although the fuzzy images make it difficult to say for certain, he thinks this caldera could be acting much like Kīlauea in Hawai‘i, a shield volcano that last erupted earlier this year. There might also have been accompanying lava flows, which show up in the second image as a brightened area north of the caldera, but the changing illumination makes it difficult to say for sure.

"It's not clear that there's been volcanic activity, i.e., stuff coming out of the ground," Byrne says. "It's possible that what we're seeing in their new paper is magmatic activity, i.e., the movement of magma in the subsurface."

"But either way," he adds, "this finding is a big deal!"

■ MONICA YOUNG

Read more at https://is.gd/Venusvent.



▲ Two images, the left taken in February 1991 and the right taken in October of the same year but from a different viewing angle, show a volcanic vent (Vent 2) that became bigger, changed shape, and darkened. (Vent 1 remained unchanged over the same time period.) The dashed line encircles a region that became brighter in that time period; whether these are new lava flows is still uncertain.

VOLCANO ON VENUS: NASA / JPL-CALTECH; RADAR IMAGES OF VENTS: USGS ASTROGEOLOGY SCIENCE CENTER / NASA PLANETARY DATA SYSTEM

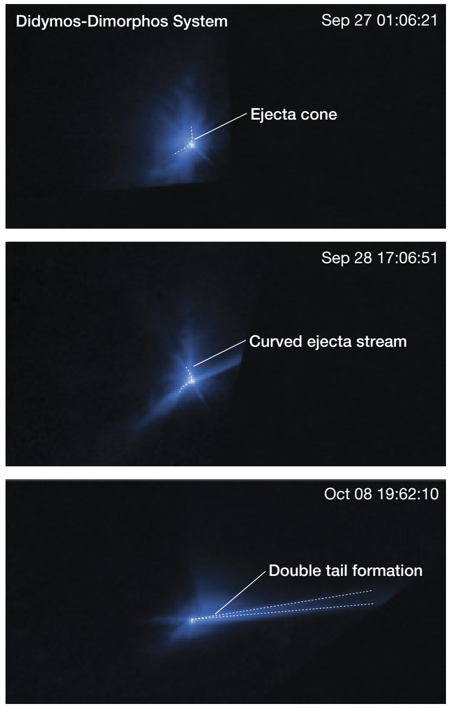
SOLAR SYSTEM

Measuring the Aftermath of an Asteroid Collision

A SET OF STUDIES published March 1st in *Nature* recount the aftermath of the September 26, 2022, intentional collision between NASA's Double Asteroid Redirection Test (DART) spacecraft and Dimorphos, the moon of the near-Earth asteroid 65803 Didymos.

A team led by Terik Daly (Johns Hopkins Applied Physics Laboratory) employed ground-based radar observations and images from DART's onboard camera to make the first estimate of Dimorphos's density: 2,100 to 2,700 kg per cubic meter. That's roughly half the density of Earth, indicating the moonlet's rubble-pile nature.

A team led by Christine Thomas (Northern Arizona University) used visible-light and radar data to narrow down the change in Dimorphos's orbital period to 33 minutes, give or take 1 minute. (This result is more precise than previous measurements, which had an uncertainty of 2 minutes.)



▶ These three panels from the Hubble Space Telescope capture the post-impact breakup of asteroidal moon Dimorphos.

These characterizations of Dimorphos enabled Andrew Cheng (also at Johns Hopkins APL) and colleagues to show that the material knocked from Dimorphos's surface during the impact ended up transferring more momentum to Dimorphos than the DART spacecraft did by itself. From images of the debris plume from the accompanying LICIACube satellite and other telescopes, they find that the ejected material bolstered DART's effect by a factor of 3.61.

Observers at large telescopes weren't the only ones watching the DART impact. Ariel Graykowski (SETI Institute) led a study of Dimorphos's light curve before, during, and after the impact, which was made possible by the 30 citizen scientists listed as coauthors on the paper. These observers, located across five continents, submitted data from their Unistellar eVscopes. From the light curve, Graykowski's team inferred the mass, speed, and energy of the ejecta, confirming Cheng's results. They estimate the ejecta carried only 0.3% to 0.5% of Dimorphos's total mass, leaving the moonlet altered but still intact.

■ LAUREN SGRO

COSMOCHEMISTRY

Some Water on Earth Might Predate the Solar System

ASTRONOMERS HAVE DISCOVERED that some of Earth's water could predate the Sun.

Observing a planet-forming disk around the infant star V883 Orionis, John Tobin (National Radio Astronomy Observatory) and colleagues report in the March 9th *Nature* the chemical composition of its water vapor.

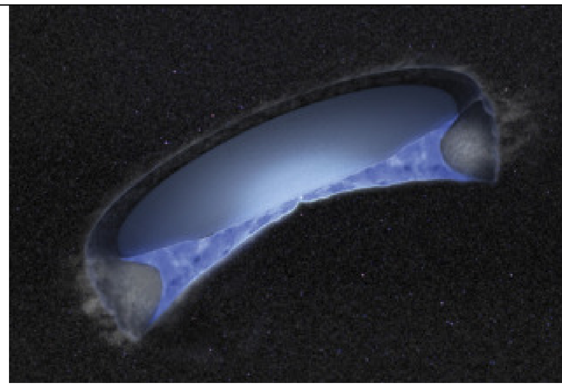
Water is arguably Earth's most distinctive feature, but where and how it formed is still up for debate (*S&T:* Mar. 2023, p. 34). The team's observations — made with the Atacama Large Millimeter/submillimeter Array in Chile — provide a missing link, showing that habitable planets can inherit a portion of their water chemically unchanged from the interstellar medium.

Most water molecules are a marriage of two hydrogen atoms and one oxygen atom. Yet sometimes one of the hydrogen atoms is replaced by an atom of *deuterium* — an isotope of hydrogen that contains a neutron in its nucleus. The ratio of the two varieties of water depends on the conditions under which they formed.

The ratio measured in the disk of V883 Orionis is roughly the same as in star-forming gas clouds and only slightly higher than in solar system comets. The result suggests water molecules remain largely unaltered as they pass from the interstellar medium and into planetary bodies.

What this means for Earth's water is still unclear — our planet's oceans have a much lower deuterium/hydrogen ratio, so comets may only have contributed a small fraction of the water.

Tobin's team was able to make the measurements of V883 Orionis because, while the water in most planet-forming disks is frozen out as ice, the young star is undergoing a dramatic outburst, heating the disk and turning its water from ice to gas.



▲ This cutaway diagram shows an artist's concept of the disk encircling the young star V883 Orionis (water vapor is blue).

The next step for Tobin's team is to look at other young systems using next-gen facilities such as the Extremely Large Telescope to better understand planet-forming disks.

■ COLIN STUART

EJECTA PLUME: SCIENCE: NASA / ESA / STSCI, JIAN-YANG LI (PSI); IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI); ARTIST'S CONCEPT OF DISK AROUND V883 ORIONIS: ALMA (ESO / NAOJ / NRAO), B. SAXTON (NRAO / AUI / NSF)

BLACK HOLES

The Milky Way's Black Hole Spaghettified a Cloud

TWO DECADES of observations show a dusty gas cloud elongating as it approaches our galaxy's supermassive black hole.

That black hole, called Sgr A*, exerts tidal forces on any objects nearby, pulling harder on the nearer side than on the farther side, stretching them out — or *spaghettifying* them — in the process.

Astronomers spotted one particular cloud, dubbed X7, in images of the galactic center taken since 2002 using the adaptive optics system on the Keck Observatory atop Mauna Kea, Hawai'i. Starting in 2006, the team also collected spectroscopic data, which give additional information about the cloud's movements.

By combining these measurements, Anna Ciurlo (University of California, Los Angeles) and colleagues show in the February 20th *Astrophysical Journal* that X7 is on its way toward the black hole. It will pass within some 3,200 astronomical units (a.u.; 18 light-days) of Sgr A* in 2036. Already, the cloud is nine times as long as it is wide.

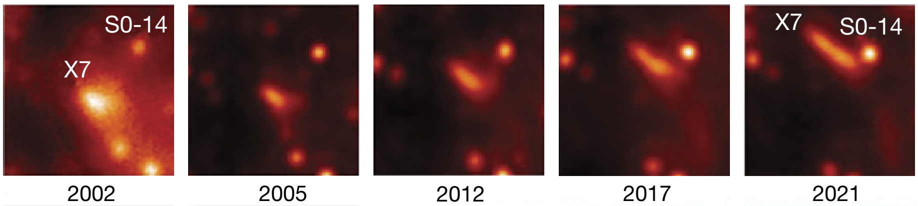
X7 won't survive its upcoming pass, so it must be younger than its 170-year orbit. Ciurlo's team therefore suggests that the gas was ejected recently when a pair of stars collided.

That scenario has support in the form of another object: a star cocooned in dust known as G3, whose orbit is surprisingly similar to X7's. G objects are thought to be products of stellar mergers. If so, X7 might represent the dust and gas expelled during the birth of the merged star at G3's core.

Stefan Gillessen (Max Planck Institute for Extraterrestrial Physics, Germany), who wasn't involved in the study, agrees with Ciurlo and colleagues, calling the study "very nice work." He adds that this kind of gaseous lump might represent a typical meal for Sgr A*. However, whether we'll see the supermassive black hole feed on the 50 Earths' worth of mass that the cloud contains depends on how long it takes to flow into the dark maw.

"For sure we will see how X7 is torn apart by the black hole," Ciurlo says. "After that, who knows? We'll be watching!"

■ MONICA YOUNG



▲ Images from the Keck Observatory show the elongation of a gas cloud over two decades. Each frame is 1 arcsecond across. The star S0-14 is labeled for reference.

LIGHT POLLUTION

Satellite Trails Mar Hubble Images

WHEN SPACEX LAUNCHED its first Starlink satellites in 2019, and astronomers realized just how bright they would be, CEO Elon Musk glibly tweeted that telescopes would simply have to go to space. Only it turns out that, depending on their orbits, space observatories aren't safe from light pollution either.

A new accounting of satellite trails in Hubble Space Telescope images, published March 2nd in *Nature*, shows that the chance of satellites affecting an image has doubled to 6% over the past two decades, largely before the Starlink era. The study serves as a baseline for comparison against future studies, in which the impacts of Starlink and other satellites will become more noticeable.

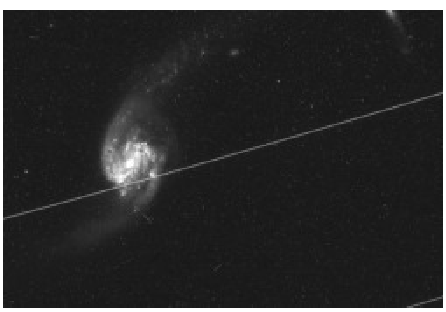
The team, led by Sandor Kruk (Max Planck Institute for Extraterrestrial Physics, Germany), started with comments on an online forum run by the Hubble Asteroid Hunter citizen-science project. Volunteers perusing images for short, curved asteroid trails noted other image anomalies, such as the long, straight streaks of satellites. Kruk and colleagues used this assortment of satellite trails to train two machine-learning algorithms, which then picked out satellite streaks from observations taken between 2002 and 2021.

Kruk's team found that the increase in satellite trails (50%) roughly corresponds to the increase in number of satellites (40%). Kruk's team estimates that satellites will interfere with at least a fifth and perhaps up to half of all Hubble images within the decade.

Other telescopes, such as ESA's Characterising Exoplanets Satellite (CHEOPS) and NASA's Near-Earth Object Wide-field Infrared Survey Explorer (NEOWISE), also conduct observations from low-Earth orbit. Studies of satellites' impacts on these space observatories are in the works.

Kruk and others have acknowledged that while some satellite trails can be removed, that isn't always possible. That's why, on March 20th in *Nature Astronomy*, John Barentine (Dark Sky Consulting) and colleagues instead proposed that governments regulate the number of satellites launched into near-Earth space. Restrictions of the objects allowed at certain altitudes, they write, may be the only way forward for sustainable space.

■ MONICA YOUNG & JAN HATTENBACH



◀ When satellites pass through a telescope's field of view, they leave behind trails, such as in this Hubble image.

CLOUD ELONGATION: A. CIURLO ET AL. / UCLA GCOI / W. M. KECK OBSERVATORY; SATELLITE STREAK: NASA / ESA / KRUK ET AL. / *NATURE* 2023 / CC BY 4.0

INTERSTELLAR OBJECTS

‘Oumuamua’s Odd Behavior, Explained

AN ASTROCHEMIST and an astronomer may have just explained the unusual orbit of the interstellar visitor 1I/‘Oumuamua (*S&T:* Oct. 2018, p. 20).

Jennifer Bergner (University of California, Berkeley) and Darryl Seligman (Cornell University) propose that the object was emitting hydrogen picked up during its time between the stars, offering a relatively simple explanation to a puzzle that has previously prompted some outlandish claims.

The true nature of ‘Oumuamua, discovered in 2017, wasn’t immediately obvious. It resembled a pancake in shape, and although initially classified as a comet, it didn’t have a visible tail or coma. One thing that did make it more comet-like was the way it was decelerating as it went away from the Sun; that is, it slowed on its way out, but not in the way expected if only gravity were in play. But without any signs of cometary activity, the normal mechanism behind such motion didn’t seem to fit.

Bergner and Seligman put forward a straightforward scenario in the March 23rd *Nature*. Cosmic radiation cooked the comet as it traveled through interstellar space, Bergner explains. As cosmic rays penetrated tens of meters into the ice, they converted 20 to 30% of the water molecules (H_2O) into molecular hydrogen (H_2). This trapped hydrogen was then released when the Sun warmed the comet.

Bergner and Seligman found that such outgassing is negligible for most comets. It only powered ‘Oumuamua because this object was so small, and astronomers on Earth wouldn’t have seen any associated activity.

Artist’s illustration of 1I/‘Oumuamua

“It probably won’t settle all debate around this object,” says Alan Fitzsimmons (Queen’s University Belfast), who was not involved in the research, “but it provides a coherent picture of ‘Oumuamua based on current knowledge, without resorting to exotic or even fanciful theories.”

Fitzsimmons thinks we could see this mechanism play out in small comets from the Oort Cloud. With facilities like the Rubin Observatory and the Extremely Large Telescope due to see first light in the next five years, we may not have to wait too long for answers.

■ COLIN STUART

IN BRIEF

Prebiotic Compounds on Ryugu

Prebiotic compounds previously found in meteorites, such as uracil (one of the four nucleobases in RNA) and niacin (vitamin B_3), have now turned up in pristine samples from the asteroid 162173 Ryugu, confirming their extraterrestrial origin. While meteorite analysis over the last decade has suggested that compounds essential for life exist in space, these space rocks can pick up contaminants as they fall to Earth. On the other hand, the sample that Japan’s Hayabusa 2 probe carefully collected during its visit to Ryugu should have little terrestrial contamination. Yasuhiro Oba (Hokkaido University, Japan), who previously found prebiotics in meteorites, led a team in using the same technique on the asteroid samples. The team reports March 21st in *Nature Communications* that uracil is present at a level of parts per billion in two samples taken from Ryugu. While this concentration is lower than previously found in some other meteorites, Oba says that might be because the parent bodies of the meteorites and of Ryugu experienced different chemical histories.

■ JEFF HECHT

Read more about the discovery at https://is.gd/Ryuguprebiotics.

2028 Launch for Rosalind Franklin Rover

The Rosalind Franklin rover, part of the European Space Agency (ESA) ExoMars program, has weathered delays due to technical issues, the COVID-19 pandemic, and the Russia-Ukraine War. On March 13th, ESA announced a “rebirth” for the mission, with a new launch date: October 2028. A looping trajectory will put the rover on Mars two years later, during spring in the planet’s northern hemisphere. Originally, Russia was going to provide the Proton rocket that would have brought the rover to Mars, as well as the Kazachok lander that would have delivered the rover to the Martian surface. However, due to Russia’s invasion of Ukraine, ESA formally terminated the mission’s cooperation with the nation’s space agency, Roscosmos, in July 2022. Europe is now building its own lander, which will no longer carry a science package. NASA, which was originally part of ExoMars but pulled out in 2012, is stepping in again, too. The U.S. agency has requested $30 million to support the mission in FY2024; the agencies are still working out longer-term costs. In addition to providing landing-engine elements, NASA could also provide launch services and radioisotope heater units, required to keep the rover warm during cold Martian nights. In the meantime, an infusion of 500 million euros ($540 million) over the next three years from ESA’s governing Ministerial Council will keep the project afloat.

■ DAVID DICKINSON

New Planets in Our Neighborhood

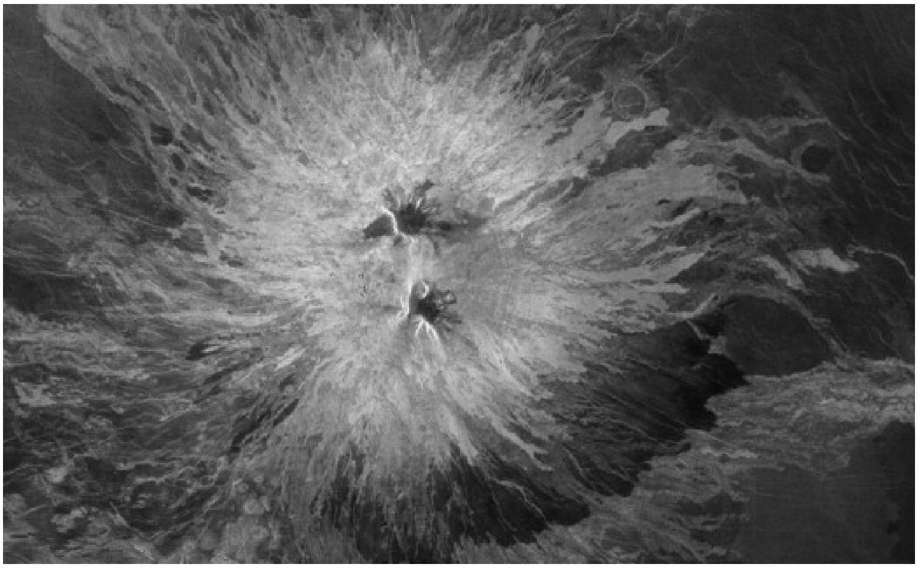
A planet-hunting consortium that designed the CARMENES instrument on the 3.5-meter telescope at the Calar Alto Observatory in Spain has released data on more than 50 worlds within 65 light-years of Earth. The consortium published visible-light observations of more than 350 stars in the February *Astronomy & Astrophysics* (additional near-infrared observations are forthcoming). The catalog includes the discovery of 33 new planets, confirmation of 26 planets found in previous transit surveys, and re-analysis of 17 known planets. Crunching the statistics, project scientist Ignasi Ribas (Institute of Space Studies of Catalonia, Spain) and colleagues find that there are 1.4 planets for every star, consistent with the occurrence rate found by the Kepler mission. Four of the new planets are likely rocky and in their stars’ *habitable zones*, meaning they could host liquid water on their surfaces. On the other end of the spectrum, the team also found gas giants orbiting extremely low-mass stars, challenging planet-formation models.

■ ARWEN RIMMER

ESO / M. KORNMESSER

Venus Lives!

Don't disbelieve the hype: New evidence for active volcanic vents on our sister planet is convincing.



▲ Magellan radar image of the Venus volcano Sapas Mons and its ancient lava flows. Another volcano shows signs of active volcanism.

"FINALLY! Scientists Find Active Volcano on Venus." Okay, *S&T* headline writer, you've got my attention (see page 8). When I first saw headlines making this claim, I was excited but wary: Scientists analyzing orbital radar images from our sister planet have actually discovered a volcanic vent that clearly changed size and shape? I had to read the peer-reviewed paper, but . . . wow!

There's a special thrill in finding something moving and changing on the surface of another planet. We've photographed plenty of ancient, cratered surfaces on the Moon, Mercury, Mars, and many asteroids and moons. Yet some of the most memorable planetary images capture those rare times when we catch something in the act: a volcano erupting off the edge of Io; a recent landslide or dust-devil track on Mars; the flash of an impact on the Moon.

One place we've long hoped to see some surface change or motion is Venus, our nearest planetary neighbor and in some important respects Earth's closest twin. Our planet's continuous surface churning is driven by heat from its hot, partially molten interior. We expect Venus, nearly the same size and density, to have similar heat flow, so it should be active.

For decades we've gathered circumstantial evidence for active volcanism there. We've observed the amount of sulfur dioxide (a volcanic gas) fluctuating in the high atmosphere, as if fed from unseen eruptions. The Magellan mission, "seeing" the surface through the clouds with radar, mapped wide-ranging volcanic landforms. Some looked quite young. But are they? In the early 2000s, Venus Express showed that some of the freshest-looking volcanoes have infrared signatures consistent with the rocks being younger than the surrounding plains. Recent lava flows?

My favorite hint is one you can see with your own eyes. Venus is so bright because of those highly reflective sulfuric-acid clouds. But chemical reactions with surface minerals would remove all that sulfur in about 10 million years — unless something is feeding sulfuric gases into the atmosphere, maintaining the cloud decks.

In 2014, news outlets also declared active volcanoes on Venus. They reported on a series of bright spots in the infrared, as seen in archived Venus Express data. One could interpret those spots as heat from lava flows.

Given all this, when I first saw those recent headlines about newly discovered volcanic activity, I was prepared for another "Well, maybe" response. Mind you, I'm pretty sure there are active volcanoes. But I don't want this particular result to turn into another "NASA Discovers Water on Mars . . . Again" situation. So before I read the scientific paper (see **https://is.gd/Venusactive**), I thought "This had better be good."

It *is* good. A round volcanic vent about a mile across on the side of a large volcano, observed again eight months later, is noticeably larger and elongated. Something has obviously changed in the before-and-after images (see the pair on page 8). There has been flow or collapse. This volcano is not extinct. Color me convinced.

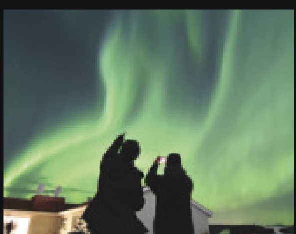
We can explain away all the other evidence for volcanism, but here a picture is worth a thousand words, or megabytes of data. Of course, there's so much more to learn — we don't know how common such changes are or how the level of activity compares to Earth's — and we need to stay tuned for the multiple Venus missions planned for early next decade (*S&T:* May 2022, p. 12). But seeing is believing. Venus has a beating heart.

> There's a special thrill in finding something moving and changing on the surface of another planet.

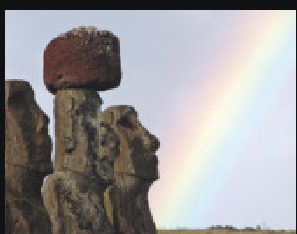
■ **DAVID GRINSPOON** is author of *Venus Revealed: A New Look Below the Clouds of Our Mysterious Twin Planet*.

NASA / JPL

OTHER BUCKET-LISTERS:



Iceland Aurora Adventure
Oct. 7–14, 2023



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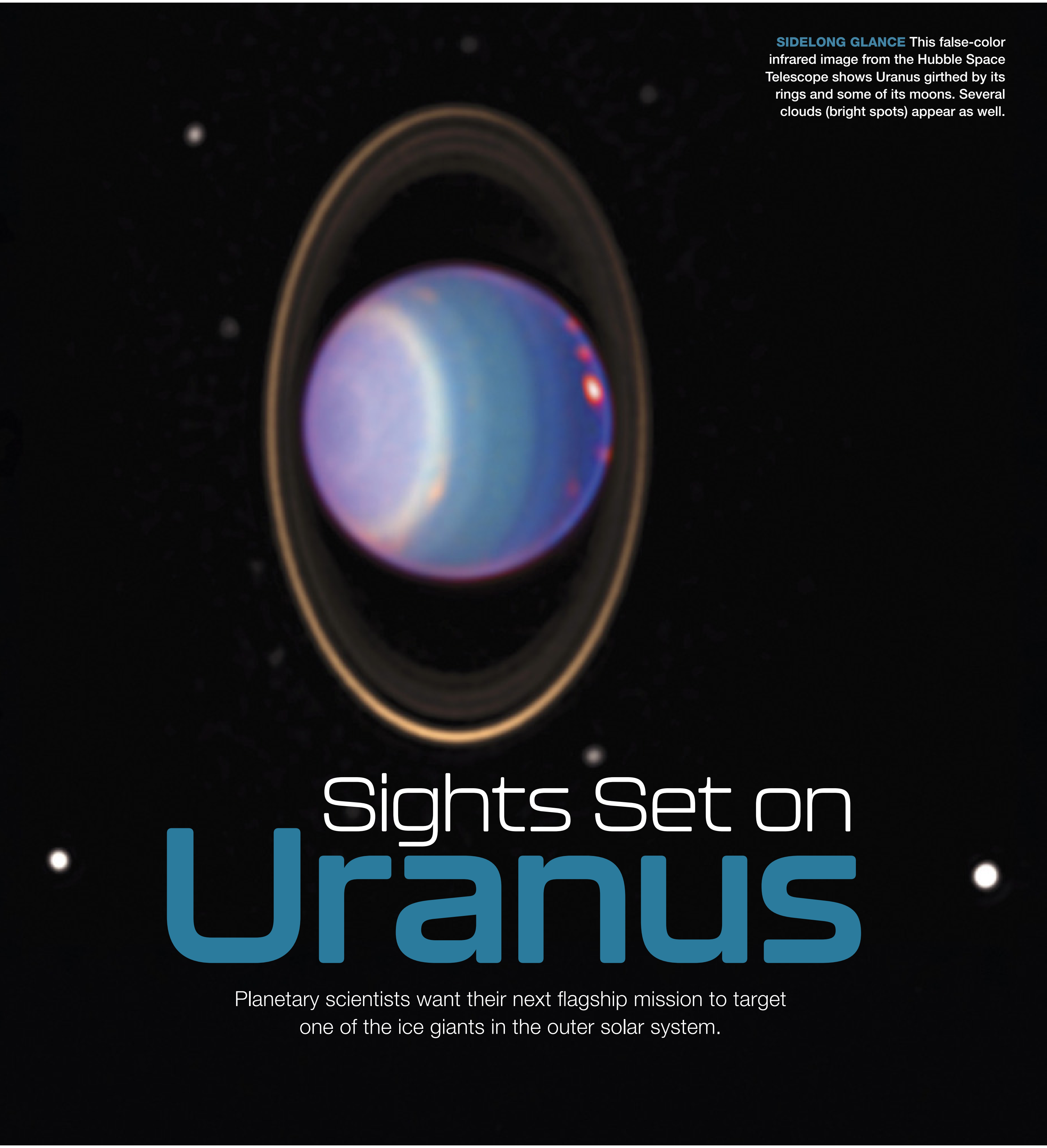


SIDELONG GLANCE This false-color infrared image from the Hubble Space Telescope shows Uranus girthed by its rings and some of its moons. Several clouds (bright spots) appear as well.

Sights Set on Uranus

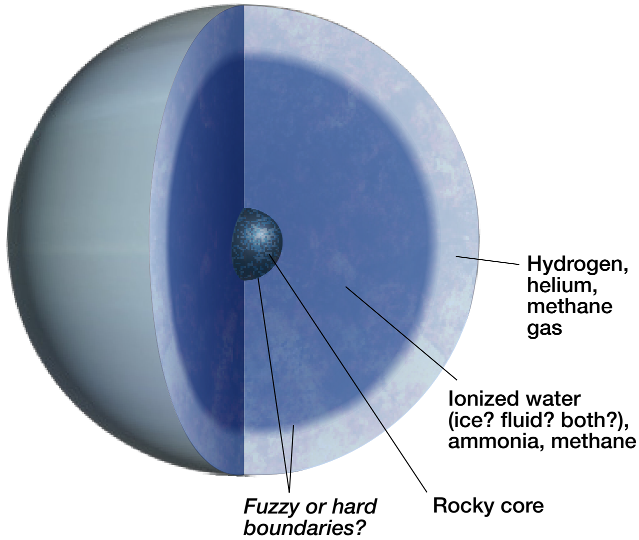
Planetary scientists want their next flagship mission to target one of the ice giants in the outer solar system.

Uranus gets no respect. It is the butt of puerile jokes. Its smooth globe has been called bland and boring. So it surprises people when I tell them that of all the places in the solar system where we could send a spacecraft, I want us to go to Uranus most.

In January 1986, when I was 11-going-on-12, photos from the Voyager 2 flyby of Uranus and its moons reached Earth. I was mesmerized. Uranus was featureless, but it was a gorgeous aquamarine blue (my favorite color). Its moons were unlike anything I'd seen before: dark worlds seamed with mountains and chasms, strikingly different to the similar-size moons of Saturn.

Inspired by this alluring world, I went on to become a planetary scientist. Since then, we've sent spacecraft to every other planet except Uranus and its fraternal twin, Neptune. We've studied the geology of the moons of Jupiter and Saturn, and even of comets and Pluto, but we haven't returned to those distant blue planets or their moons.

In the next decade, Uranus might finally get its turn. As part of the once-a-decade survey conducted by the National Academy of Sciences — the report that usually sets the to-do list for NASA's next planetary missions — scientists have declared that the development and launch of a Uranus Orbiter and Probe (UOP) is their highest priority for the next flagship mission. If NASA launches it in the early 2030s, as proposed, this mission could "deliver an in situ atmospheric probe and conduct a multi-year orbital tour that will transform our knowledge of ice giants in general and the Uranian system in particular," the committee wrote. Given that NASA usually follows decadal recommendations (with missions like Perseverance, currently roving Mars, and Europa Clipper, now under construction), we'll likely put a spacecraft in orbit around Uranus by the 2040s.

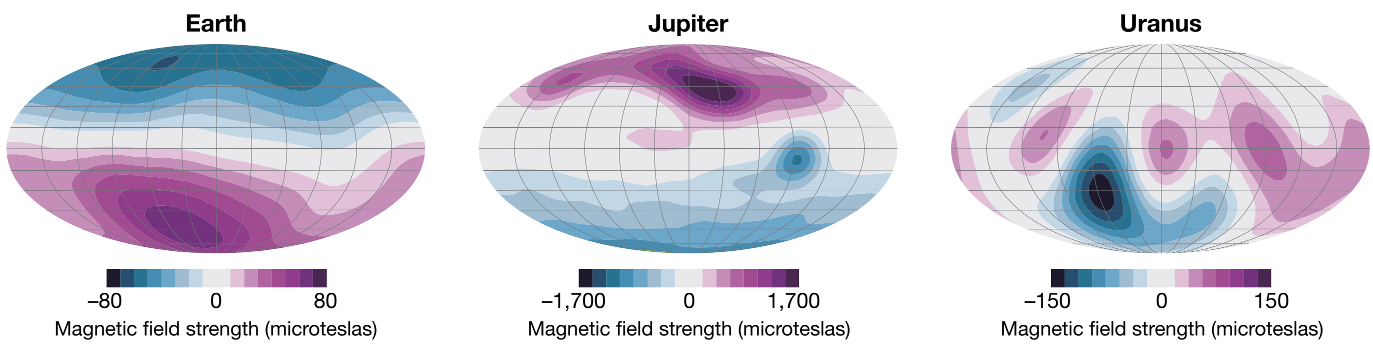


▲ **MYSTERIOUS INTERIOR** Hypotheses for the structure and composition of Uranus's interior vary, but they generally favor a rocky core overlaid by a water-rich mantle (at least partially in the form of superionic ice, although perhaps there's an "ocean" layer, too), with a gaseous envelope dominated by hydrogen, helium, and methane.

What's Inside Uranus?

Since the 1930s, we've suspected that Uranus and Neptune are made mostly of ice. ("Ice" refers to materials that are typically liquids or gases on Earth but are frozen in the outer solar system, including water and other lightweight molecular compounds like methane and ammonia.) By that time, astronomers had measured each planet's mass, volume, and *moment of inertia*, a measure of how concentrated the mass is toward the planet's center. Meanwhile, spectroscopy had shown that objects in the solar system appeared to have one of three main compositions: solar material (mostly hydrogen and helium), rock, and ice.

At that time, German astronomer Rupert Wildt asked: What if solar stuff, rock, and ice were the main ingredients for everything in the solar system, including the giant planets' interiors? Wildt calculated how much of each material would be needed in concentric layers to balance each world's mass, volume, and moment of inertia. He predicted that all four planets had rocky cores, surrounded by a layer of ice, but that Saturn and Jupiter had thick hydrogen-helium atmospheres that made up most of their mass, while Uranus and Neptune were mostly ice with only thin hydrogen-helium envelopes.



▲ **STRANGE FIELDS** The global magnetic fields of the solar system's terrestrial and gas-giant planets are predominantly *dipolar*, with a north (pink) and south (blue) pole that largely align with the planets' rotation axes. (Yes, Earth's north magnetic pole is currently at the geographic south pole.) Jupiter's field has more complexity than Earth's. But Uranus's field differs dramatically, with multiple poles grossly misaligned with the rotation axis. Neptune's field is similarly convoluted.

URANUS (FACING PAGE): NASA / JPL / STSCI; URANUS CUTAWAY: LEAH TISCIONE / S&T; MAGNETIC FIELDS: K. M. SODERLUND AND S. STANLEY / *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A* 2020

We haven't learned much else about the interiors of the two ice giants since then. All the cutaway drawings you've ever seen that show the layered interiors of Uranus and Neptune (including the one on the previous page) are based on almost as many assumptions as Wildt made, nearly a century ago. State-of-the-art models for ice-giant interiors produce implausible compositions having anywhere from 3 to 20 times as much ice as rock, even though bodies that formed even farther from the Sun, like Pluto and Eris, have far more rock than ice.

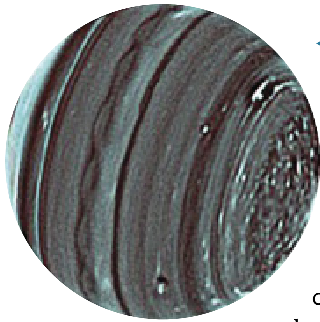
We do know, however, that something strange is happening inside the ice giants. Voyager 2 discovered that the planets' magnetic fields look nothing like what we'd expect. Other worlds we've explored have *dipolar fields*, like a bar magnet, with a north pole and a south pole. But Uranus and Neptune's fields are multipolar, snarled things that aren't even remotely symmetrical, with north and south "poles" popping out of the planet in several locations. Furthermore, the fields emanate not from the core but from the mantle above it.

The current best hypothesis to explain the weird magnetic fields is that the dynamo that generates them originates within *superionic ice*, an odd form of water that might exist at the high temperatures and pressures within the ice giants' mantles. In superionic ice, hydrogen nuclei (that is, protons) can move freely within a solid lattice of oxygen nuclei, much as electrons move freely within a conductive metal. But we know neither the magnetic fields' shapes nor the planets' internal structures and temperatures well enough to connect magnetic-dynamo theory with our scant observations. To make matters worse, Neptune radiates 10 times more internal heat than Uranus, and we don't know why or how to explain their different heat flows with the same theory.

It's all a giant mystery.

Exploplanetary Ice Giants

Scientists have new reason to care about the ice giants, thanks to the planetary systems they've found around other stars. More than half of all known exoplanets have diameters between one and four times that of Earth, putting them between Earth and Uranus (*S&T:* Feb. 2022, p. 20). Mass and density estimates make these worlds look even stranger. Instead of being clearly rocky (like Earth) or hydrogen-helium dominated (like Saturn), exoplanets with diameters in between have densities all over the map, from rock-like to ice-like to gas-like. Without knowing their moments of inertia — the crucial piece of information that Wildt used to estimate the compositions of our solar system's giants — scientists can only guess what any given exoplanet is made of. And if we don't know their compositions, we can't figure out how this most common size of planet formed, nor can we



◀ **NOT A BLAND BALL** These near-infrared composites each combine more than 100 images from the Keck II telescope to reveal subtle patterns on Uranus. White features are thick, high-altitude clouds whereas bright blue-green ones are more transparent, akin to Earth's cirrus clouds. Reddish tints mark deeper cloud layers.

ADAPTED FROM L. A. SROMOVSKY ET AL. / *ICARUS* 2015

understand why they're so diverse.

The exoplanet revolution has fundamentally changed the way space agencies view the goals of planetary exploration. Previously, exploration goals were driven by destination: We go to Venus, or Jupiter, or Pluto primarily to study those worlds — although, of course, the science we achieve at one world is applicable to others. The new idea is grander: We don't travel the solar system just to tour those destinations. We go to other worlds to answer open questions about planetary systems generally, and we select destinations based on their potential to answer those questions.

Just as this perspective shift has turned the international scientific community's gaze back to Venus (*S&T:* May 2022, p. 12), it has also fueled support for a mission to one of our neighborhood ice giants.

Why Uranus, Why Now?

Scientifically, Uranus and Neptune are equally interesting, but they are not the same. Although similar in mass and color, one (Neptune) releases more heat from its interior, compared to the sunshine it receives, than any planet in the solar system; the other (Uranus) emits the least. Their ring systems are very different: Uranus has thin, dense rings, studded with a dozen closely packed satellites, while Neptune's rings are sparse and clumpy. Uranus also has a set of spherical, mid-size icy moons to explore; only one of Neptune's moons is round, but it's big and likely captured from the Kuiper Belt. A compelling case could be made for the scientific value of sending the first ice-giant orbiter to either one.

But Uranus is a lot closer to us than Neptune is, orbiting some 19 astronomical units from the Sun instead of Neptune's 30 a.u. That alone tips the decision in Uranus's favor: Less distance to travel means a shorter cruise and therefore less fuel and money spent en route. Closer to the Sun also means less of a climb out of the solar gravity well; the same launch vehicle can deliver a heavier spacecraft to Uranus than to Neptune.

Choosing Uranus has other practical advantages, particularly the possibility of a Jupiter gravity assist. Through 2033, Earth, Jupiter, and Uranus will periodically align in such a way that a spacecraft could use the giant planet's gravity as a boost toward Uranus, shortening the flight of a lightweight craft to as few as eight years, although a heavier orbiter capable of addressing the full list of scientists' questions would take at least 12 years to arrive.

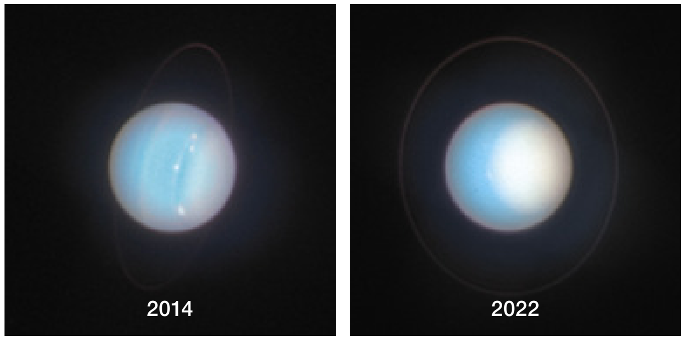
There's one more reason to go to Uranus first: seasons.

Uranus orbits the Sun while lying on its side (why? we don't know), and it experiences extreme illumination changes as a result. In January 1986, Uranus was close to its southern summer solstice, with the Sun overhead at a latitude of 82° south. Uranus's southern hemisphere baked in continuous sunlight. The continuous radiation built a thick haze that obscured atmospheric activity beneath it. At the same time, the north poles of both planet and moons stayed in perpetual darkness, hiding them from Voyager 2's view.

Nearly 22 years later, in December 2007, Uranus passed through an equinox. The shift of seasons brought dramatic changes to Uranus' atmosphere, which lit up with storms and belts visible from Earth. Now, in 2023, atmospheric activity is shutting down again as the planet approaches its 2030 solstice, plunging the southern hemisphere into darkness.

The next equinox comes in February 2050. So the best chance to see the most dynamic state of Uranus's atmosphere, to study the rings at a full range of solar illumination angles, and to see all of the satellites lit pole-to-pole with sunlight comes in the 2040s, as Uranus approaches equinox. Each year after 2050 will hide more and more of the north poles of both the planet and its moons in winter darkness and will produce more atmospheric haze, making Uranus harder to interpret.

Neptune poses no such time crunch. Its less extreme axial tilt makes arrival at a specific time of year less urgent, and although its weather changes as seasons shift, it produces dark storms and bright "scooters" year-round. Neptune's year is so long, with each season lasting 40 years, that any mission we launch in the next half-century will see the planet at a different season than Voyager 2 did.

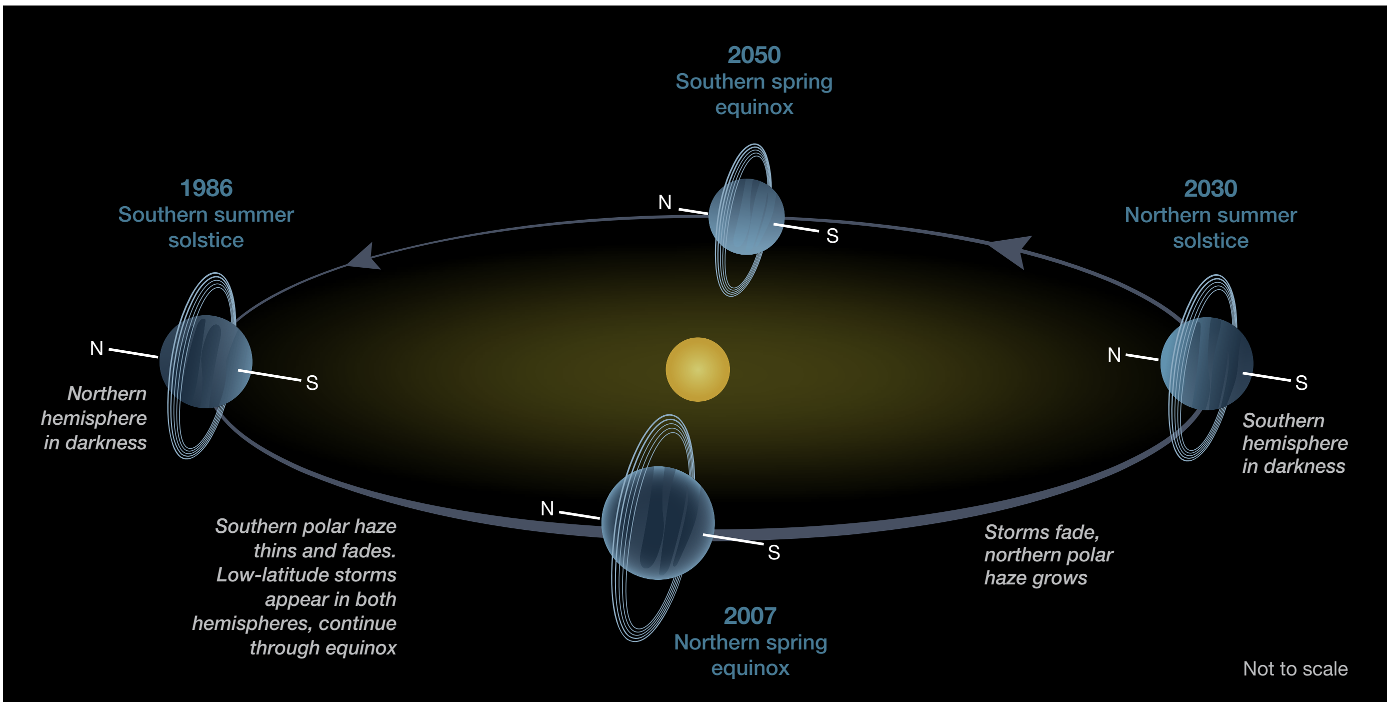


▲ **CHANGING SEASONS** *Left:* In November 2014, seven years after the northern hemisphere's spring equinox, storm clouds of methane ice crystals appear at mid-northern latitudes. *Right:* Eight years later, with the Sun beating down on high northern latitudes, a thick, smog-like haze has built up over the north pole.

What Would a Mission to Uranus Look Like?

At the moment, the proposed Uranus mission is mostly a list of questions, both about the science and the spacecraft design. NASA hasn't yet committed to sending it, either. Nevertheless, planetary scientists are throwing themselves into the discussion, advocating for which mysteries they most want to solve and how they would learn the answers.

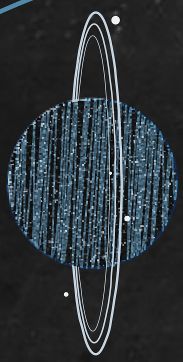
We can speculate on what the mission might look like,



URANIAN SEASONS Because of its rotation axis's extreme tilt — 98° from the orbital plane — Uranus experiences dramatic seasonal changes over the course of its year. When Voyager 2 flew by in 1986, the northern hemisphere was in complete winter darkness. By sending a spacecraft to rendezvous with the ice giant in the 2040s, scientists hope to catch the storms and weather systems that pop up around equinoxes.

URANUS IMAGES: SCIENCE: NASA, ESA, STSCI, AMY SIMON (NASA-GSFC), MICHAEL H. WONG (UC BERKELEY), IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI); ORBIT DIAGRAM: BEATRIZ INGLESSIS / S&T, SOURCE: M. SHOWALTER AND M. GORDON / SETI INSTITUTE

VOYAGE TO URANUS Scientists' favored mission scenario has the orbiter and probe launching from Earth in 2031 or 2032, making a loop around the Sun, and then swinging by Earth for a gravity assist to shoot it toward the outer solar system. A Jupiter flyby would give it another boost, rocketing it toward Uranus for a mid-2040s arrival. Once there, orbiter and probe would investigate every aspect of the planet, rings, and moons; here are some of the questions on scientists' list. The primary mission at Uranus would last 4½ years.



ORIGINS

When, where, and how did Uranus form?

Did a catastrophic impact knock Uranus sideways?

RINGS

What are the rings made of?

How old are they?

What sculpted them into their current configuration?

How do they relate to the moons?

MAGNETOSPHERE

Why is the magnetic field so complex?

How does it interact with the solar wind?

How does it affect the upper atmosphere, moons, and rings?

Probe

MOONS

How old are the moons, and how did they form?

What is their internal structure and composition?

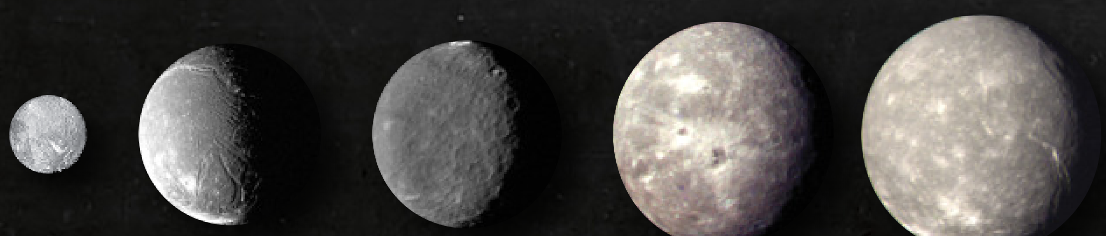
Is there current geological activity?

Do any have subsurface oceans?

Have the surface compositions changed with time?

How do the moons interact?

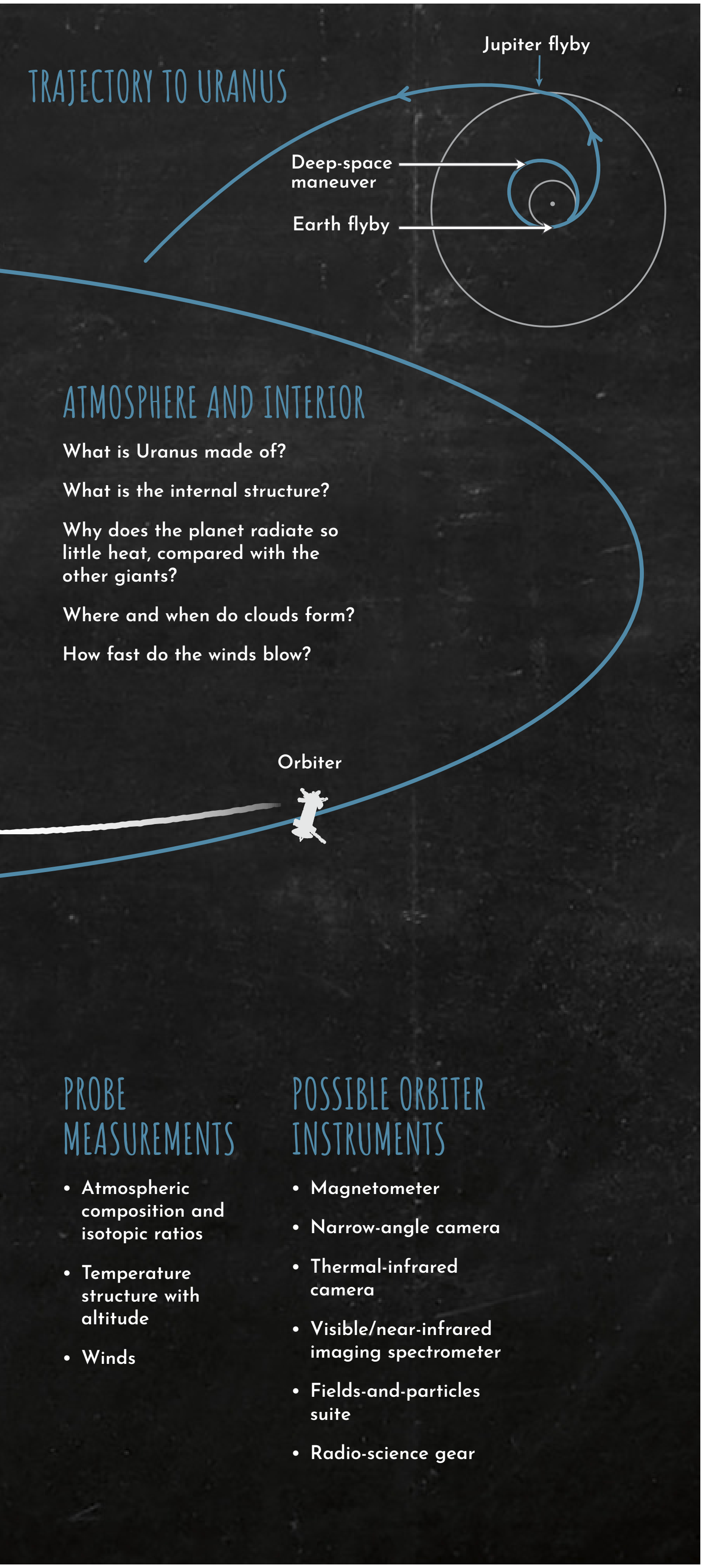
EARTH'S MOON
3,476 km



MIRANDA 470 km | ARIEL 1,160 km | UMBRIEL 1,170 km | OBERON 1,522 km | TITANIA 1,578 km

▲ **READY FOR OUR CLOSE-UPS** The only surface images we have of Uranus's five largest moons come from Voyager 2, and they're small and sometimes blurry. But they show signs of resurfacing. Sizes are diameters.

INFOGRAPHIC: BEATRIZ INGLESSIS / S&T; MOONS: NASA / JPL (5)



based on the study submitted to the decadal survey. The study concluded that we know so little about ice giants that we need a flagship mission with an atmospheric probe, like Galileo was at Jupiter and Cassini at Saturn, to investigate the planet's system from interior to magnetosphere, rings, moons, and all. The recommended flagship would cost at least $2 billion. Worried about asking NASA for too much and ending up with nothing, scientists have also proposed less expensive, $1 billion scenarios that could achieve a subset of the flagship mission goals: a Juno or a New Horizons analog, rather than a Cassini.

There are literally tens of thousands of potential mission scenarios, mixing and matching rocket types, gravity assists, cruise times, payload sizes, and onboard power supplies. Because the questions about Uranus are so broad, the instrument suite must cover a wide range of capabilities. It's useful to compare the potential Uranus mission to the recent Cassini flagship and New Horizons' fast flyby: The Uranus orbiter's instruments will have similar scope to those on Cassini, but thanks to advancements in miniaturization and automation that enabled the New Horizons, Dawn, and Lucy missions, they will be much smaller and require less power and data volume.

Since the most important questions about Uranus relate to its interior structure and composition, it's almost certain that the mission would carry a magnetometer to probe the gnarly magnetic field and glean information about the planet's guts. As on every mission, radio science will reveal the distribution of mass within the planet through ultra-precise tracking of the spacecraft, and we'll study Uranus's atmospheric composition, temperature, and pressure by beaming the craft's radio signal through the atmosphere back to Earth.

The choices among other instruments depend on budget, available mass and power, and scientific focus. A fields-and-particles suite including energetic-particle detectors, plasma spectrometers, and other devices could study the charged atoms whipped up by the magnetic field and the dust knocked off the moons and rings. Spectrometers in visible and near-infrared wavelengths could investigate the composition of moons, rings, and planet, while a thermal-infrared instrument would be able to map surface temperatures and study the nightsides of planet and satellites from the heat they radiate. Narrow- and wide-angle cameras could perform distant and close-in imaging, making maps of the moons, rings, and planetary storms. If we're very lucky, we might witness the effects of an impact like that of Shoemaker-Levy 9 on Jupiter in 1994 and study the stuff dredged up from below.

A probe would be costly in terms of mass and budget; making physical room for a probe and taking on its complexity and risk would necessarily reduce the capability of the mothership that deposits it into Uranus. But a probe is essential to nail down answers to the questions surrounding how and when Uranus formed, and from what materials. For example, one model for solar system formation, *gravitational instability*, would leave Uranus and Neptune with fractions of the ele-

ments heavier than helium that are about 100 times higher than those found in the Sun. A different model suggests that Uranus and Neptune originated at an ice-giant sweet spot, the *CO snowline*, at a solar distance where carbon monoxide condensed into a solid but nitrogen was still a gas. If this is true, then Uranus will have 100 times as much carbon and oxygen as the Sun does, but a much smaller enhancement of the other elements. A probe's sensitive measurements could help differentiate among these scenarios by revealing various elements' abundances and isotopic ratios. It could also tell us the atmospheric structure, where clouds form, and how deep the winds go.

The Mission Scenario

As put forth for the decadal survey, the UOP concept study requires a sizable rocket. It assumes that the giant Space Launch System will not be available, favoring an expendable Falcon Heavy instead. (A reusable Falcon Heavy gives too small a boost.) The ideal mission scenario is a launch in 2031 or 2032, with a gravity-assist flyby of Earth two years later, then another past Jupiter, reaching Uranus 12 or 13 years after launch. That scenario gets you 5 tons of spacecraft in orbit around Uranus. An SLS launch vehicle, if available, could cut the travel time substantially, down to as little as six years.

A later launch without a Jupiter flyby would require some combination of a longer cruise (up to 18 years, beyond which the decaying power supply from the radioisotope generators becomes an issue), more fuel-guzzling rocket maneuvers (increasing risk and reducing the amount available to steer the science orbits), lower spacecraft mass (limiting science instruments and maneuvering fuel), the addition of a Venus gravity assist (imposing challenging thermal requirements on the spacecraft that reduce the mass budget), and/or help from a solar-electric propulsion stage (adding cost and complexity).

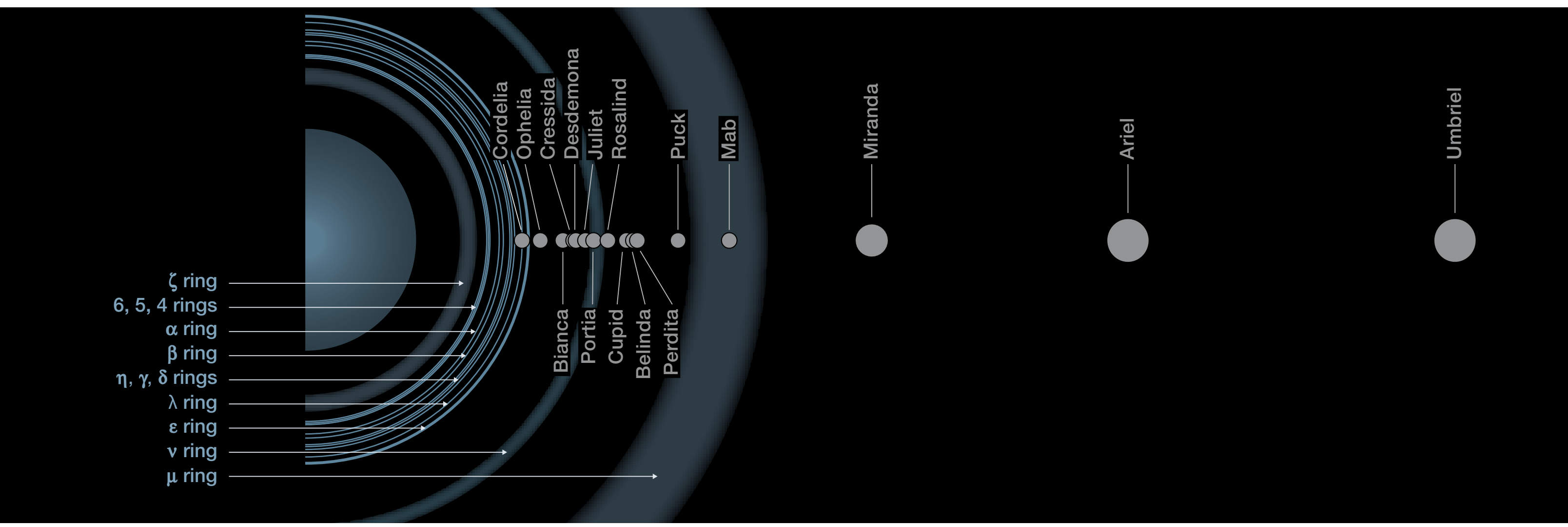
Spacecraft can release their probes on approach or after entering orbit. Both options come with tradeoffs. The UOP concept has the spacecraft first enter a highly elliptical orbit and then launch the probe, like Cassini did with Huygens. This setup would enable the team to select the entry point for scientific reasons rather than trajectory ones. As soon as the probe mission was over, the orbiter would use another rocket burn to pull closer to the planet, entering an orbit optimized for planet, ring, and satellite science.

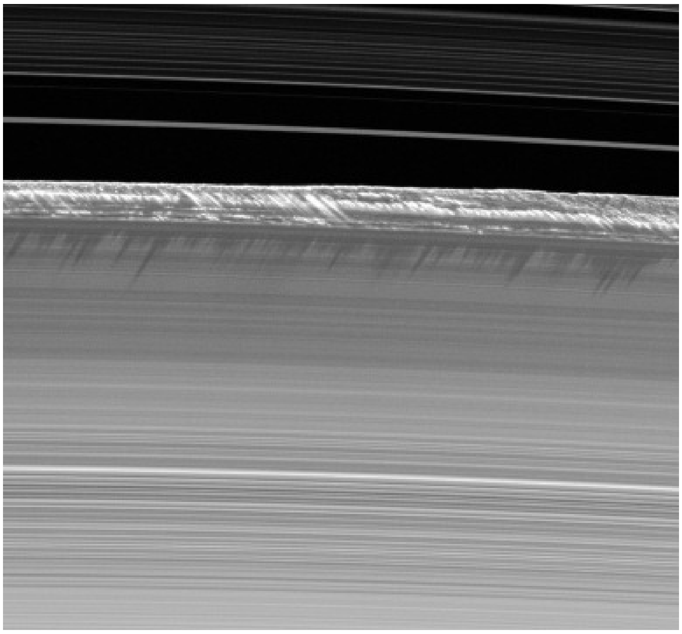
At first, the orbiter's path around Uranus would be tilted out of the ring plane. Such a tilted orbit is great for study of the magnetosphere, rings, and poles, but it doesn't enable many encounters with the icy moons — some of which appear in Voyager 2 images to have been resurfaced by geological activity; they might even have subsurface oceans. Ariel, Umbriel, Titania, and Oberon are all large enough to provide tweaks to an orbiter's path around Uranus. So the post-probe-mission rocket burn would target one of those moons — likely the most massive one, Titania — to set up a resonant orbit, meeting the moon in the same location every time the spacecraft passed through the ring plane. Over time, moon flybys would slowly change the orbit, just as Cassini did at Saturn with flybys of Titan. Eventually, the spacecraft would equatorialize its orbit, traveling within the ring plane.

A ring-plane orbit makes the rings largely invisible — because they're so thin, it'll be like looking along the edge of a razor — but allows pole-to-pole monitoring of planetary weather. Flying in the ring plane also generates far more opportunities to observe the moons, including mutual events (where one moon occults another from the craft's perspective). These events are necessary for precisely determining the moons' orbits, which in turn would reveal the satellites'

▼ **CROWDED SYSTEM** A collection of small and mid-size moons huddles around Uranus. (We've omitted the outer nine moons; they follow elongated, highly inclined orbits.) Some rings are dusty, others icy. It's unclear what sculpts the narrow ones. The many small moons just outside the main rings orbit so close together that they're in danger of collision or migrating toward the planet — in fact, the current set of moons might be fairly recent, part of a destruction-and-creation cycle that supplies ring-forming debris. Moon sizes are not to scale.

BEATRIZ INGLESSIS / S&T





▲ **RING PEAKS** This Cassini image reveals vertical structures rising abruptly from Saturn's icy B ring. The peaks tower as high as 2.5 km (1.6 mi) above the rings and may be "splash-ups" created by passing moonlets. They appear stark thanks to the low illumination angle of equinox, when sunlight shines obliquely along the ring plane and causes structures jutting out of the plane to cast long shadows. An orbiter at Uranus might see similar structures during the planet's own equinox.

NASA / JPL / SPACE SCIENCE INSTITUTE

masses and gravitational tugs on each other. The spacecraft could spend a long time in such an orbit; the lifetime of the mission will ultimately be limited by the waning power available from its radioisotope power source.

The end would eventually come. To prepare, the orbiter would execute multiple flybys of the innermost thousand-kilometer-size moon, Ariel — which may have the geologically youngest surface of the bunch — to pull the spacecraft into a death spiral. Finally, a rocket burn at apoapsis would reduce the orbital periapsis to one that intersects Uranus's atmosphere, burning it up in the planet's icy air. This disposal method avoids harm to any potential habitable environment on the moons.

The baseline orbital mission would last less than five years. But history suggests that once an orbiter is safely at Uranus, NASA would consider mission-extension scenarios that would send the orbiter on additional tours, perhaps studying the anti-Sun side of the magnetosphere or performing dedicated gravity-tracking flybys of moons, as Cassini did at Saturn. The availability of gravity assists from four moons at different distances from Uranus make the options nearly endless.

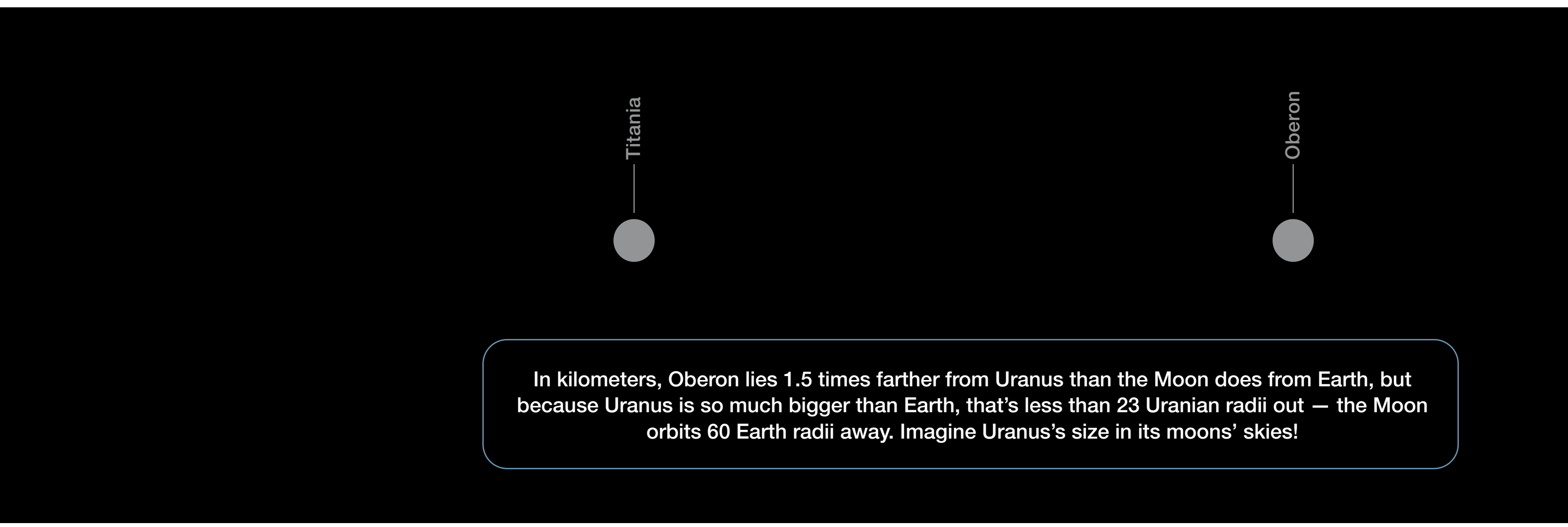
To Infinity, and Beyond!

We still don't know exactly what the first dedicated ice-giant mission will look like, or what it will discover. The scenario I've outlined here, as detailed as it is, is just one concept. It also doesn't include how other space agencies might collaborate with NASA. The European Space Agency, for example, contributed the Huygens probe to Cassini and is also considering building an ice-giant orbiter.

One thing we do know is that the scientists and engineers developing a future mission to Uranus — or Neptune — will not be the ones operating it when it arrives. The mid- and late-career scientists who have the professional standing and the time to propose future missions will be edging toward retirement by the time a spacecraft actually enters orbit. This mission will belong to today's early-career scientists.

Studying the outer outer planets requires patience, faith, and hope — an optimistic view that, two or three decades from now, today's children will be enjoying the opportunity to be the first to study a new kind of planet from orbit. These days, such optimism is a breath of fresh air. So tell your kids: It's time to probe Uranus!

■ Contributing Editor **EMILY LAKDAWALLA** is a freelance science writer and space artist based in Los Angeles. Find her work, socials, and shop at **Lakdawalla.com/emily**.



THE CUBESAT REVOLUTION by Alastair Isaacs

Tiny MIGHTY Satellites

Briefcase-size craft have become game-changers in space exploration.

It took less than 24 hours for things to go wrong. CAPSTONE, a spacecraft no larger than a microwave, had vanished from the radio waves. For the controllers back on the ground, the silence was a problem. Without radio communications, they had no way to command the craft — and no way to correct its path toward the Moon.

The Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) was a CubeSat, a class of ultra-small satellite, and researchers had intended to use it to prove the stability of a new orbit around the Moon. NASA was hoping that it would thus pave the way to something far more ambitious: the Gateway, a lunar space station that could one day host astronauts preparing to walk on the Moon.

Yet as CAPSTONE failed to respond to repeated messages, those dreams suddenly seemed at stake. Fortunately, time was on the controllers' side. CAPSTONE was on a stable trajectory and carried enough fuel to recover, should it miss the planned correction maneuver. They were confident, too, that the spacecraft had deployed its solar panels, giving it enough power to stay alive while they troubleshot the problem.

▲ **CAPSTONE** A team member installs solar panels on the CAPSTONE spacecraft. Despite multiple mishaps, the little satellite successfully reached the Moon in late 2022.

DOMINIC HART

In the end, that time proved enough. Engineers regained communications within days, successfully executing the maneuver as planned. To blame, they realized, was a software bug triggered by a badly formatted command, which had left the radio unresponsive and the satellite uncontrollable. The satellite's own automatic recovery processes cleared the fault, enabling the craft to continue its journey. Four months (and another mishap) later, in November 2022, the spacecraft arrived and became the first CubeSat to orbit the Moon.

Necessity Is the Mother of Invention

The concept of small spacecraft like CAPSTONE first emerged in the 1990s. At the time, the idea that they would one day venture to the Moon, or even beyond, would surely have seemed ridiculous. They were intended as mere teaching aids, a way for two professors — Jordi Puig-Suari (then California Polytechnic State University) and Bob Twiggs (then Stanford University) — to give their class hands-on experience with designing and building satellites.

Normally this design process took years, with a price tag stretching into the tens of millions of dollars. Even getting satellites off the ground was expensive. Launch costs at the time started at $5,000 per kilogram, and many satellites weighed several tons. What was needed, they realized, was a kind of minimalist satellite, something small, cheap, and lightweight — something that a master's student could put together in two years, with time to spare before graduation.

The result was the CubeSat: a small box, measuring 10 centimeters (4 inches) per side, containing only the most essential ingredients for survival in space. As long as they kept the basic dimensions of the cube, students were free to fill the satellites with whatever equipment they wanted. They could even stack the cubes, building up larger CubeSats from individual units.

Crucially, Puig-Suari and Twiggs also designed a simple deployer for their CubeSats. This box could carry any CubeSat

BON VOYAGE Three Japanese CubeSats deploy from the International Space Station. They tested various university-built instruments, including a drag chute to help deorbit spacecraft faster.

PEGGY WHITSON

on almost any rocket. It also meant that CubeSats didn't need an expensive dedicated rocket. Instead they could hitch a ride, taking advantage of space unused by larger satellites. When a group of six CubeSats launched in 2003, they rode on the Russian Rokot-KM, soaring into space with three far larger satellites. Later launches would do the same, using rockets as diverse as the Falcon 9, India's PSLV, and even the gigantic Space Launch System.

Before long, CubeSats caught the imagination of entrepreneurs, who realized the satellites offered a way to overcome the high-cost barrier to launching a space business. One could, for example, kit out a dozen or so CubeSats with cameras, put them in orbit, and begin selling imagery of the world below. Companies like Planet Labs and SkyBox Imaging (later sold to Planet) did exactly that, building up constellations of dozens, then hundreds, of satellites. Others employed them to monitor the atmosphere, to track aircraft and ships, and to hunt for smugglers and illegal fishing vessels.

A handful have even been used for astronomy, turning their sensors toward the stars instead of toward Earth. One, the Arcsecond Space Telescope Enabling Research in Astrophysics (ASTERIA), demonstrated technologies for exoplanet surveys. It became the smallest spacecraft to detect a planet around an alien star. Another, HaloSat, mapped X-ray radiation from across the sky, enabling researchers to probe the galactic halo around the Milky Way.

There is, however, a catch. CubeSats may be capable, but they are also notoriously unreliable. One study by NASA, published in 2019, concluded that for every five CubeSats launched before 2017, two had failed in their mission goals. A significant proportion of CubeSats appear to be dead on arrival, never checking in with their operators after reaching space.

"It's a matter of time, resources, and experience," says Michael Swartwout (Saint Louis University), who maintains a detailed database of CubeSats. Many small satellite designers, he argues, have to be willing to sacrifice performance for cost — a consequence of limited budgets and time pressures imposed by shared launches with fixed deadlines. "If you don't have the opportunity to delay the launch," he says, "you often end up doing the final check-outs after launch."

Since those check-outs often reveal unexpected problems, CubeSats must be designed to be reparable in orbit. Problems like those encountered by CAPSTONE, he says, can be fixed as long as the spacecraft is ready for it. In some cases that means uploading new software; in others, it means making sure the spacecraft can stay safe even if something doesn't work

◀ **CAREER LAUNCHER** CubeSats have given students and early-career scientists hands-on experience with building satellites. From top to bottom: A NASA intern works on the Advanced Electrical Bus, which launched in 2018 to test a new high-wattage electrical system; St. Louis University students work on a satellite that launched in 2013 to test a tiny infrared camera; CalPoly students test the Planetary Society's LightSail satellite, which in 2015 demonstrated the feasibility of using sunlight to propel tiny spacecraft.

NASA / GRC / BRIDGET CASWELL; ST. LOUIS UNIV.; CALPOLY: THE PLANETARY SOCIETY (3)

as expected. Unfortunately, it also means accepting a higher chance of degraded performance or even failure.

Still, despite these drawbacks, CubeSats have revolutionized the way universities, companies, and researchers survey our planet and the galaxy around us. Though they are risky, they are cheap. They can thus host experiments and technologies that might otherwise never find their way into space.

Until recently, however, that revolution has been constrained to a few hundred miles high. As CubeSats venture farther from Earth, might they soon change the way we think about exploring the solar system, too?

Next Stop: Mars

An early glimpse of how the future of planetary exploration may look came in 2018. That year a pair of CubeSats — MARCO-A and MARCO-B — lifted off with NASA's Insight, a lander heading to Mars. Guided by their internal navigation and propulsion systems, they flew toward the Red Planet. As they did, they became the first CubeSats to leave Earth's realm and head into deep space.

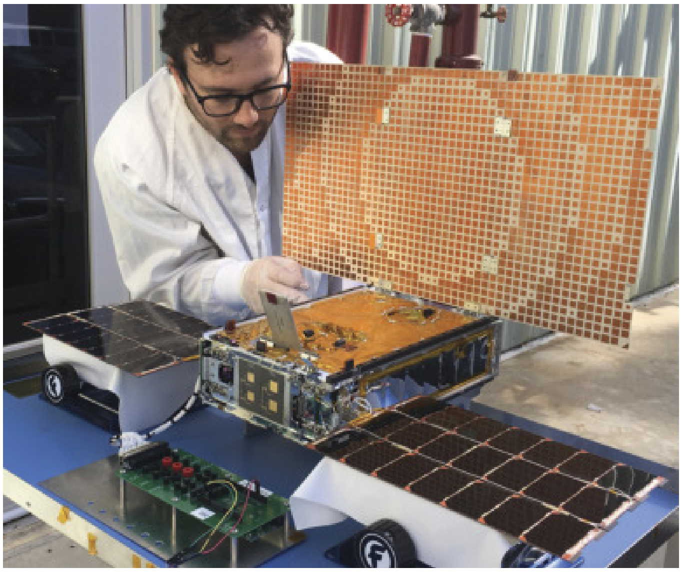
As CubeSats go, the MARCO satellites were sophisticated beasts. Each was six units in size — that's to say, made of six basic cubes stacked in a rectangular shape. They were equipped with propulsion systems, allowing them to steer their way towards the Red Planet. Both also deployed large antennas, enabling them to send messages to Earth and receive instructions back.

Despite this sophistication, however, the MARCO CubeSats were still small, weighing some 14 kg (30 pounds) each. NASA, aware that CubeSats do not always operate as planned, especially when far from Earth, sent two. At least one, they hoped, would survive all the way to Mars. If it did, then the CubeSat would help relay data from Insight's descent to the Martian surface, transmitting signals back to Earth across 157 million kilometers (97.5 million miles) of space.

In the end, that caution proved unnecessary: The pair reached Mars without major issues, showing that CubeSats are capable of interplanetary flight. They were able to relay data from Insight, giving operators an almost (bar the speed-of-light delay) real-time view of the landing. And for reasons probably more symbolic than practical, MARCO-B snapped a picture of Mars as it flew past.

That, then, was a success. Operators kept contact with both CubeSats in the weeks after the Mars flyby, downloading as many data files and images as they could. As they drifted farther from Mars' orbit, NASA started thinking about other targets, checking to see if any asteroids happened to lie along their trajectories.

But then something curious happened: MARCO-A suddenly stopped responding to controllers. No one has been able to fully establish why. NASA's report on the mission speculates about the nature of possible failures, but it notes that everything looked more or less fine up until the loss of contact. MARCO-B, meanwhile, suffered from a worsening fuel leak, an issue that may have sent it into an unrecoverable spin. Whatever the problems were, they spelled the end for the MARCO mission. The two CubeSats are now lost in space, too small and distant to ever be found.



▲ **MARS-BOUND** An engineer tests the solar arrays on one of the MARCO CubeSats. The pair of satellites flew along behind NASA's Insight lander on its cruise to Mars.

CUBESATS: JOHNSON SPACE CENTER; MARCO-B: NASA / JPL-CALTECH

From Failures to Fleets

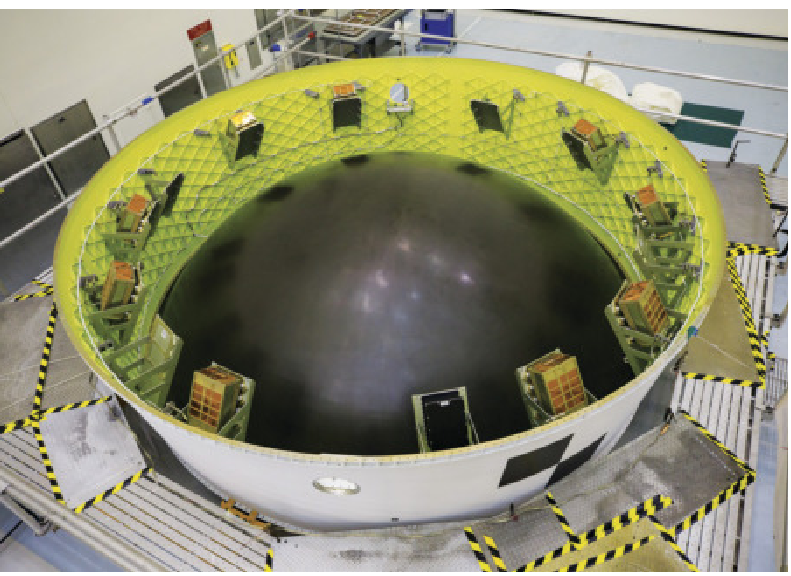
This somewhat sad ending highlights the issues that have haunted many deep-space CubeSats. The Artemis 1 CubeSats — a set of 10 small satellites launched with the Orion capsule in November 2022 — suffered a failure rate as high as 40% (*S&T:* Apr. 2023, p. 10). One — NASA's NEA Scout CubeSat — never responded to its operators' commands. Others suffered component failures or seemed low on power, issues that prevented them from achieving their goals.

NEA Scout, propelled by a solar sail, was intended to fly to the asteroid 2020 GE. Once there, it would have examined the 18-meter-wide (59-foot-wide) asteroid at close range, helping astronomers understand a class of asteroid too small to observe from Earth and never before visited by a larger spacecraft. Omotenashi — a Japanese CubeSat — was supposed to impact the Moon, an event that would have made it the first Japanese spacecraft to reach our natural satellite. Yet it, too, failed, unable to point its solar panels at the Sun long enough to charge its batteries.

Professor Swartwout cautions against taking the lessons of Artemis 1 too harshly. "I would not draw broader conclusions," he says, pointing out that the CubeSats faced battery issues after the long period they spent inside the rocket, repeatedly rolling out to the launch pad and back. Still, he thinks, the reliability of CubeSats, especially as they venture into more dangerous space far from Earth, remains a concern.

Last year at the Interplanetary Small Satellite Conference, Steve Matousek (JPL) painted an optimistic picture. The capabilities of small satellites, he pointed out, are rapidly improving. Propulsion, communications, and satellite lifespans are all benefiting from improving technologies, even as costs fall. Developments in electric propulsion, for example, may enable otherwise impractical deep-space missions.

▼ **ARTEMIS 1 TAGALONGS** An array of CubeSats rode inside the stage adapter between the Orion spacecraft and its giant rocket, the Space Launch System, during the Artemis 1 launch.



NASA / CORY S. HUSTON

He argued that improvements in other technologies — especially in communications, power management, and miniature sensors and instruments — will allow for small-satellite constellations around Mars within two decades.

Small bodies, such as asteroids, comets, or visitors from interstellar space, could be other targets for CubeSat swarms. Currently, Matousek said, we generally have only one viewpoint of these objects as they approach Earth. Ring them with CubeSats, however, and we could see them from multiple angles. We could even survey the moons of the outer planets with CubeSats, supporting the observations of larger, more powerful probes.

A handful of missions, indeed, have already started pursuing this approach. LICIACube, a CubeSat which flew with DART to the asteroid Didymos, is an early example (*S&T:* Sept. 2022, p. 14). When DART smashed into Didymos's small moon, Dimorphos, last year, LICIACube was on hand to photograph the impact, returning a series of images from a distance of under 80 kilometers (50 miles).

HERA, a European follow-up mission to the same pair of asteroids, will carry a pair of CubeSats named Juventas and Milani. They should help HERA survey the asteroid and the impact site with radars and cameras. Afterwards, if all goes to plan, the CubeSats will attempt to land on Dimorphos, relaying their observations back to Earth through HERA.

Interest in these possibilities is becoming more mainstream among astronomers, despite lingering concern about CubeSat performance. In its Decadal Report — an influential publication that directs much of American public spending on astronomy — the National Academy of Sciences gave a cautious nod to CubeSats. It highlighted areas in which CubeSats could benefit astronomers, particularly thanks to the crafts' fitness for rapid response and cheaper missions. CubeSats could reach targets inaccessible to more traditional probes or enable long-term observations of interesting targets — something Earth's telescopes, under high time pressure from astronomers, cannot easily offer. Still, "it remains to be seen," the panel wrote, "whether SmallSats will, in the long run, prove to be an effective platform for a range of astrophysics investigations."

The expendability of CubeSats could also prove an advantage, allowing them to venture into places more expensive satellites dare not go. One proposal, published as part of the European Space Agency's Voyage 2050 mission planning cycle, suggested sending CubeSats through Jupiter's radiation belts. This, a suicide mission surely, could return valuable data from a region too dangerous for bigger probes to enter. Another concept, developed by a team at JPL, envisioned a CubeSat "diving" through Saturn's rings, returning imagery for as long as it survives.

The Next Generation of Explorers

Perhaps the most ambitious plans, however, center on Mars. Despite decades of research and billions of dollars spent on orbiters and rovers, we still lack a clear view of the planet's

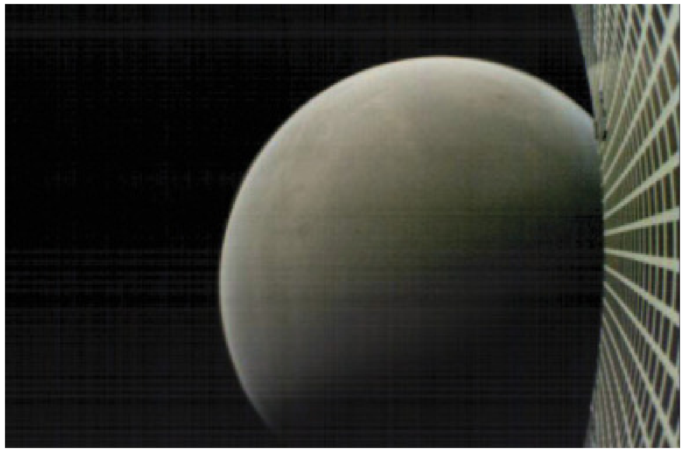
climate system. Today, just seven active spacecraft orbit the Red Planet: enough to give us daily updates on the comings and goings on Mars, but insufficient to paint a detailed picture of its weather and landscapes (*S&T:* Dec. 2019, p. 22).

Dust storms, for example, often envelop Mars' surface, shrouding the planet for months on end. These hazardous events — they've spelled the end for robotic probes, and NASA fears they may harm future astronauts — appear with little to no warning, sometimes exploding to cover the whole planet, sometimes staying small and quickly fading away. Why? We really don't know.

To find answers, a recent report argued, we need a more dynamic view of Mars. That would mean putting far more satellites in orbit around the Red Planet. Until recently such a project would have come with an extraordinary price tag. Building and running MAVEN, the most recent NASA orbiter to reach Mars, has cost close to $900 million. Multiply that by 10 or 20, and the cost of a constellation looks untenable.

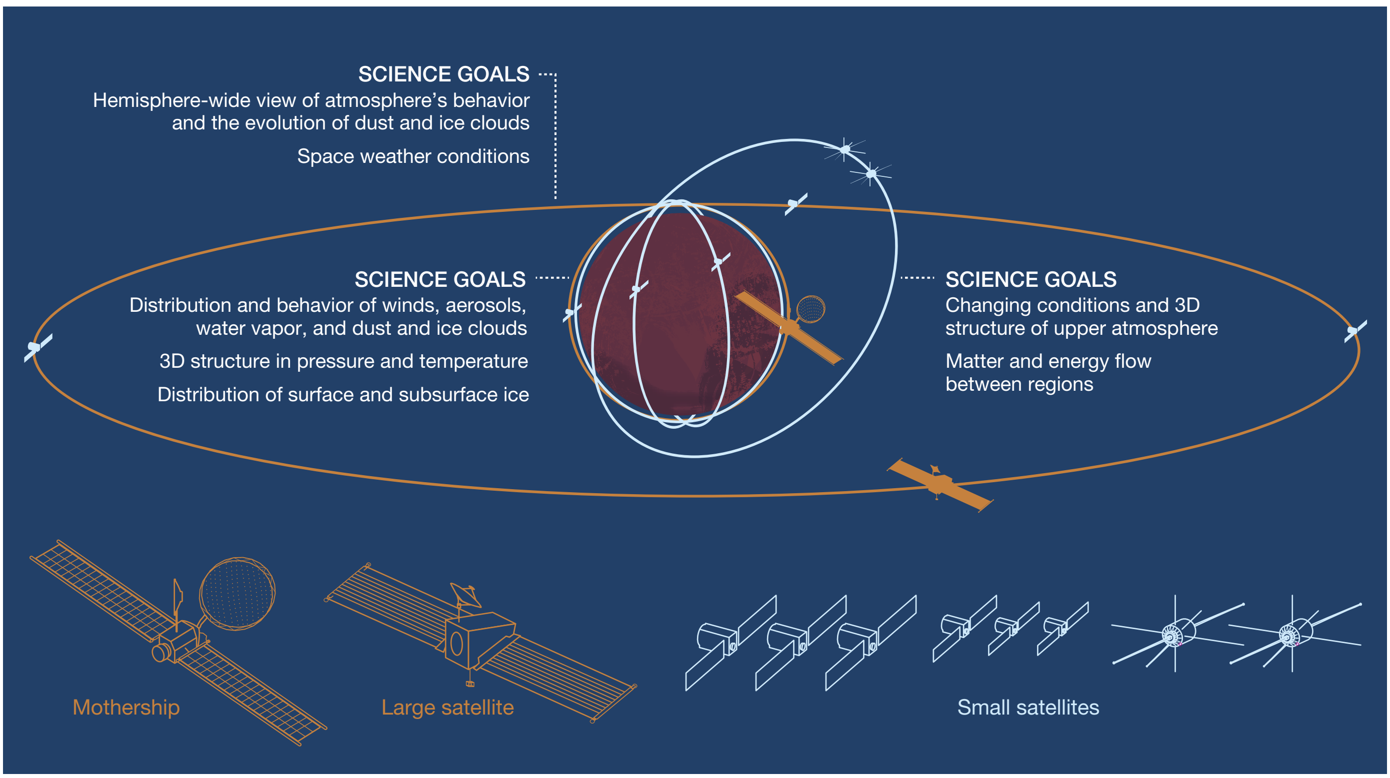
One concept sketched out by NASA, together with researchers from Berkeley and JPL, instead envisions building a constellation comprising a mix of small and large satellites. These would work in tandem to monitor Mars, giving planetary scientists a clear picture of the planet's dynamics for a far cheaper price. In all, the researchers reckon, a constellation of 10 spacecraft would cost around $3 or $4 billion to build, launch, and operate.

Ideas like this, if they ever come to pass, are at least two decades in the future. Yet they show the potential for CubeSats and small satellites to change not just the way we look at Earth, but also at the solar system around us. They promise to open a new era of exploration, giving researchers views of places long considered too risky, difficult, or expensive to explore. They may even, one day, pave the path for humans to venture far beyond Earth.



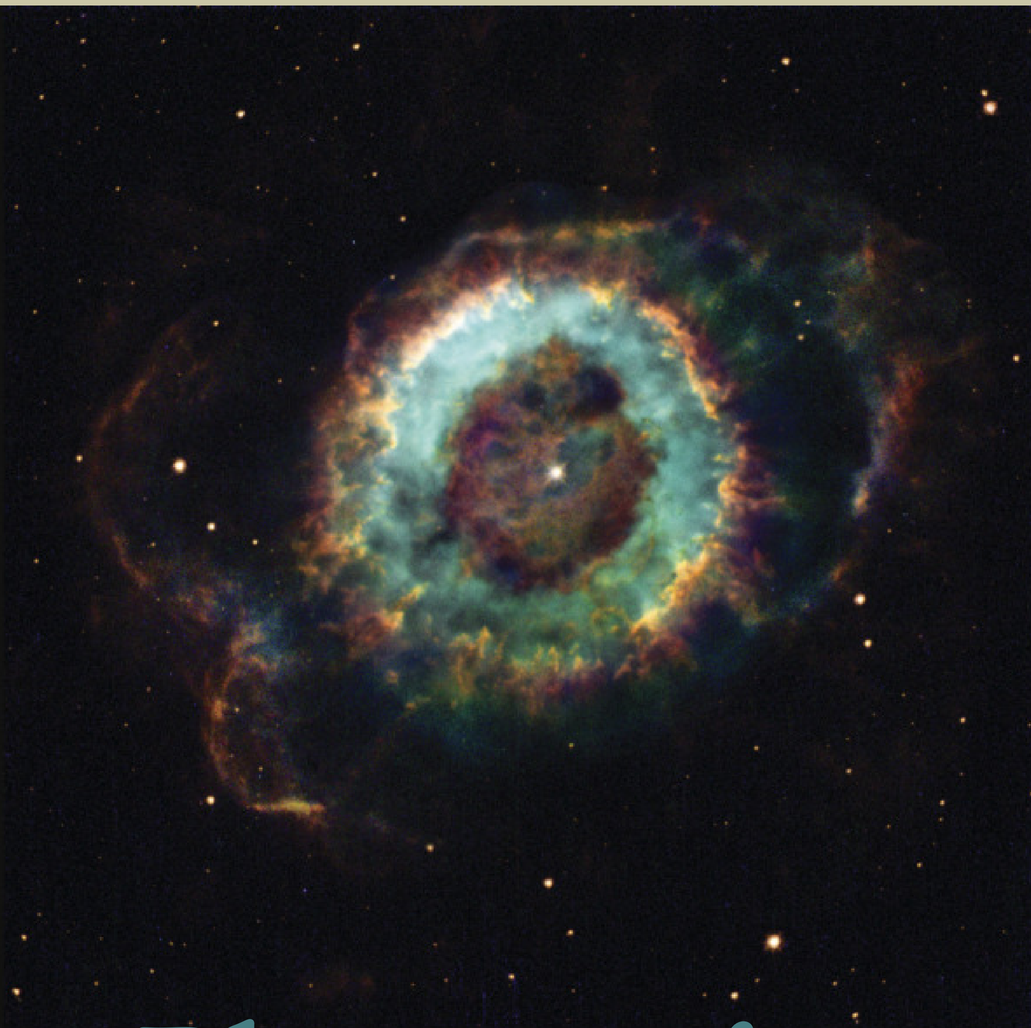
▲ **PASSING GLANCE** MARCO-B took this image of Mars from a distance of about 7,600 km (4,700 mi) during its November 2018 flyby, while the CubeSat was flying away from the Red Planet.

■ **ALASTAIR ISAACS** is a space missions engineer based in Spain. He has worked on several European satellite projects, including space telescopes and SmallSat constellations.



▲ **MARS FLEET** One mission concept would place 10 satellites of different sizes in three types of orbits around Mars. This arrangement would enable detailed observations of atmospheric conditions on both regional and global scales.

CUBESAT'S IMAGE OF MARS: NASA / JPL-CALTECH; MARS MISSION CONCEPT: BEATRIZ INGLESSIS / *S&T*, SOURCE: R. LILLIS ET AL. / MOSAIC MISSION CONCEPT STUDY 2020



Planetaries from the Driveway

Follow this guide to learn how to snag a clutch of planetary nebulae under city skies.

In the April 1995 issue of this magazine, I described how I located and observed 39 planetary nebulae with my 3½-inch telescope from my driveway despite being surrounded by the "vast urban sprawl" of Houston's skyglow and "various small but overilluminated cities." My night skies have become considerably brighter over the years. But, using techniques I developed in the 1990s, I can still manage light pollution. Observing in the shadow of a light barrier as well as ancillary equipment such as a black head drape and narrowband filters all help me maximize my observing opportunities.

▲ **THE LITTLE GHOST** The Hubble Space Telescope's stunning image of NGC 6369 in Ophiuchus reveals the ghostlike clouds and tendrils of the star that once was. North is upper left.

NASA / ESA / THE HUBBLE HERITAGE TEAM / STSCI / AURA

Of course, there's no substitute for pristine skies, but for me those seem to exist only in the realm of fond childhood memories and in faraway places. So, I make do with what I have.

Following my initial foray, I embarked on two other surveys: The first involved 38 planetaries down to magnitude 12.3 that I hunted with my 3½-inch Questar, and the second focused on 32 more down to magnitude 13.2 that I observed

with my 7-inch Questar. Here I'll describe how I snagged eight of my favorites, which are suitable for summer and autumn nights. And I've observed all of them from my driveway.

I've selected this subset from my original surveys either because I considered them interesting or simply because I find them pretty. Some of the planetary nebulae were faint fuzzies that taxed the limits of my instruments. A few were so mundane it seemed that only professional astronomers showed any interest in them. At least two turned out to be exotic objects and even spectacular in images taken with the Hubble Space Telescope (as on page 28). And three more surprised me.

Besides my two Questars and several eyepieces, I also used an O III filter at one time or another to observe these objects. On several occasions I applied the handheld "blink" technique to differentiate planetaries from dim stars. I also used an eyepiece with an occulting bar to reduce glare if a bright star was near my chosen target. In addition, the bar provided a reference point during "blinking."

Now, let's turn to our targets. I hope you enjoy them as much as I did.

From Ophiuchus to Lyra via Scutum

Perhaps the moniker "Lonesome" Ghost would suit **NGC 6369** better than its accepted nickname, Little Ghost. On my first visit to this planetary nebula with my 3½-inch telescope, I noted that it's practically the only luminous object of interest in a 21′-wide eyepiece field, save for 9.6-magnitude HD 158233 located 5.6′ south-southwest. An O III filter enhanced the planetary's 11.4-magnitude, 38″-wide disk, but I couldn't make out that it was annular, nor could I detect its 15.9-magnitude central star. Some years later, I used the 7-inch at magnification 160× yielding a 17′-wide field, which revealed the nebula's bluish color and profoundly dark annulus (but I still couldn't see the central star). Look for the planetary some 2° northeast of 3.3-magnitude Theta (θ) Ophiuchi, just ½° northwest of 4.8-magnitude 51 Ophiuchi.

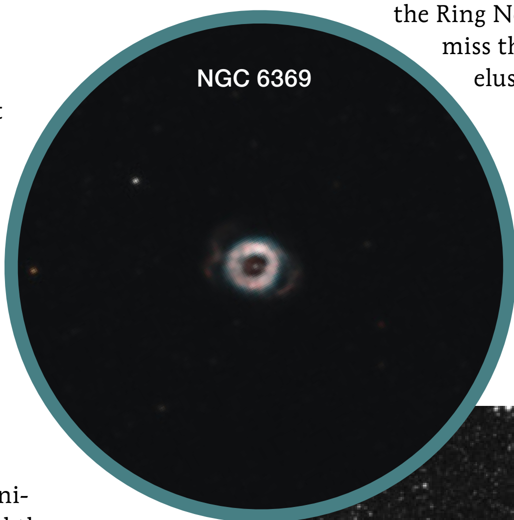
With the dense star clouds of Scutum as a backdrop, there are few reference points for locating the 12.5-magnitude, 5″-diameter **M 1-59**. However, if you start at 4.7-magnitude Delta (δ) Scuti and scan about 15½′ almost due east, you'll land in its general area. A 25′-wide eyepiece field will reveal the planetary's position between two 8.5-magnitude stars that are just a bit less than 19′ apart in a north-northeast to south-southwest direction. HD 172981, at magnitude 9.7, is about halfway between these two stars, and the planetary is 2¾′ farther southwest along the same line.

Using the 7-inch at 212× yielded a 13′ field and with the O III filter, the planetary presented a tiny, pale, bluish disk. I couldn't detect a central star, and the edge of the disk appeared smooth.

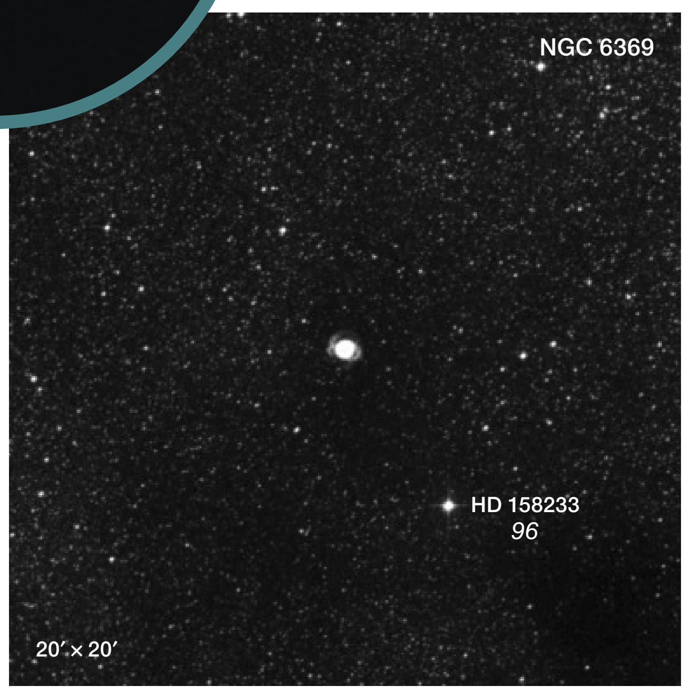
NGC 6765 is a fairly large planetary at 40″ across, but it's dim (magnitude 12.9). It lies in Lyra about midway on a line connecting Gamma (γ) Lyrae to Albireo in Cygnus. To help you pinpoint it better, look for an isosceles triangle formed by 10th- and 11th-magnitude stars labeled in the image on page 30. This micro-asterism is relatively easy to see, and it fits nicely into the 13′-wide field of my 7-inch telescope at 212×.

I used the O III filter after pre-focusing on a nearby star, and I immediately became aware of something almost dead center in the triangle. After several minutes of hyperventilation and lots of imagination, I began to believe that the planetary was actually there. Not only that but I then began to imagine that the grayish nebula was elongated, and its brighter end was pointed north-northeast almost directly towards one of the triangle stars. It turns out that it wasn't my imagination after all — I was really seeing NGC 6765!

To celebrate this find, I nudged my telescope about 4½° northwest to enjoy the satisfying sight of M57. We wish that all planetary nebulae were as big, bright, and easy to see as the Ring Nebula. But if they were, we'd probably miss the thrill of finding something more elusive like NGC 6765.



▼ **STARS LEAD THE WAY** Find your way to these targets by consulting the star chart on pages 42–43 to locate the brighter stars discussed in the text. Then, use the "pointer" stars highlighted in the finder images here to refine your search. Stellar magnitudes are presented without the decimal point, and dimensions are also given. North is up in all images unless otherwise noted.



NGC 6369 PHOTO: GARY IMM; FINDER IMAGE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Acquisitions in Aquila

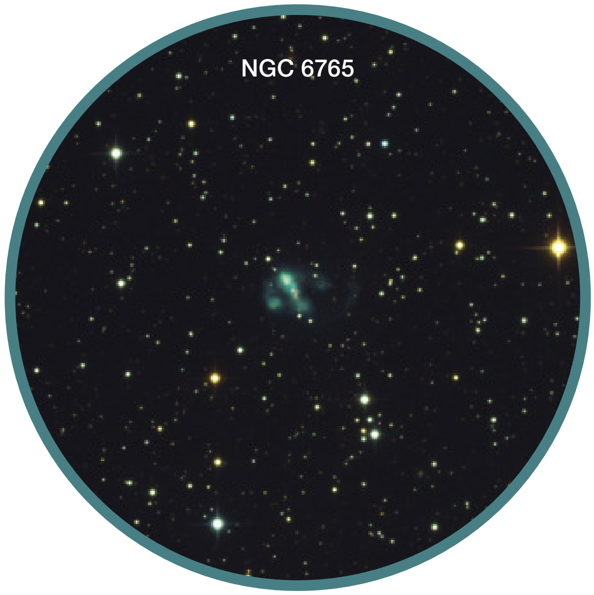
Let's slide over into Aquila, the celestial Eagle, for our next four targets. Starting at Lambda (λ) Aquilae and slewing 3° northeast will bring you approximately to **NGC 6772**. I swept around there with the 7-inch at 80× using the O III filter but couldn't see any trace of the 12.7-magnitude, 86″-diameter nebula. I consulted an online database (I use SIMBAD), and an image of the area showed three 11th-magnitude stars forming a straight line about 8′ long north of the planetary's position. I nudged this line of stars into place at the northern end of a 17′ eyepiece field at 160×.

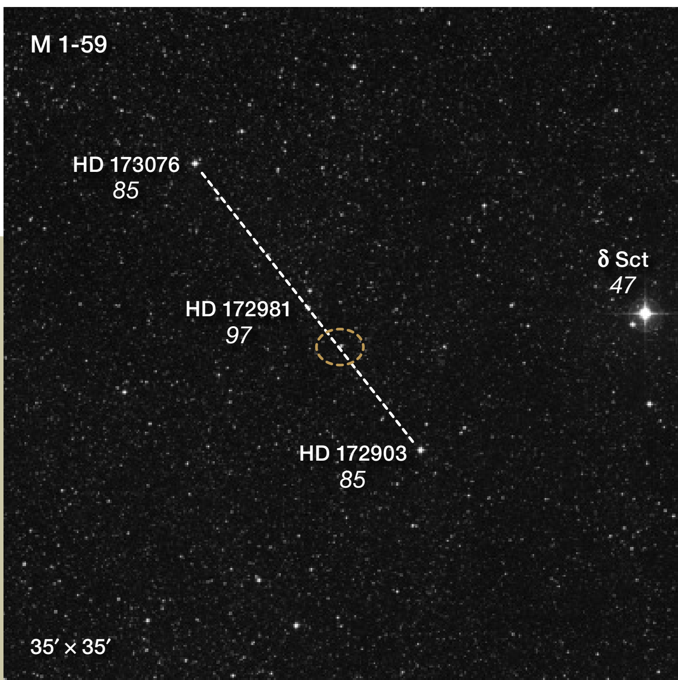
Once you've done that, locate the 10.9-magnitude star that's about 12′ southeast of the westernmost star of the trio. Draw an imaginary line connecting these two stars, and it will intersect NGC 6772. Drop another imaginary line from the 11.2-magnitude central star of the three stars north of the planetary by about 6.4′, and you'll encounter the first imaginary line. Most importantly, this brings you to the northern edge of the planetary (see the image on page 31).

Thus, having pinpointed the invisible nebula with two imaginary lines (tongue firmly in cheek), I then used every weapon in my arsenal to try to snag this elusive object. The bottom-line outcome from a multi-night endeavor was a qualified "maybe." I saw something Jupiter-sized a few times at 160× using a broadband filter with averted vision, but I could only hold it momentarily. The planetary nebula didn't respond well to the O III filter or any other time-tested method for viewing dim objects, i.e., jiggling the field or increasing contrast with magnification. So I had to leave it be.

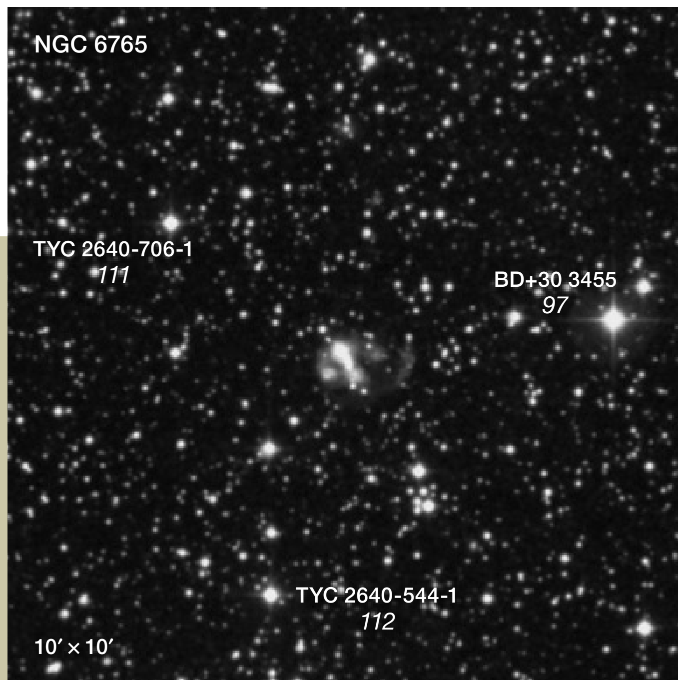
Roy Scheider, who played Police Chief Brody in the movie *Jaws*, might have commented in this situation, "We're gonna need a bigger ~~boat~~ telescope!"

Continuing on northeast from NGC 6772 by 1½° will bring you to **NGC 6778** (also known as NGC 6785). This 12.3-magnitude, 37″-wide nebula achieved a certain notori-



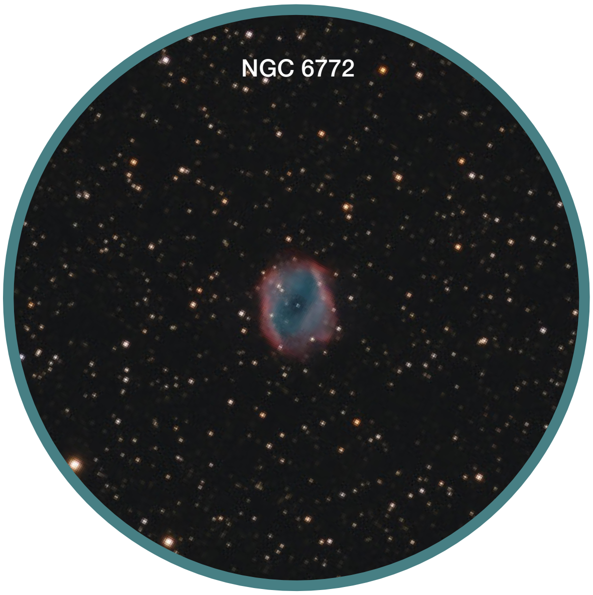


▲ **HANDY CELESTIAL LINES** In some cases stars have aligned themselves in helpful ways to guide you to your target. M 1-59 (in the dashed circle) lies directly on a line connecting three stars.



▲ **LARGE BUT DIM** NGC 6765's coordinates are in Lyra near the center of an isosceles triangle of stars that's about 6′ long on two of its sides. The brightest of the three triangle stars is 9.7-magnitude BD+30 3455, which points the triangle to the west-northwest. An 11.1-magnitude star lies 6′ east-northeast of the planetary nebula, and an 11.2-magnitude star lies 5.3′ to the south-southeast.

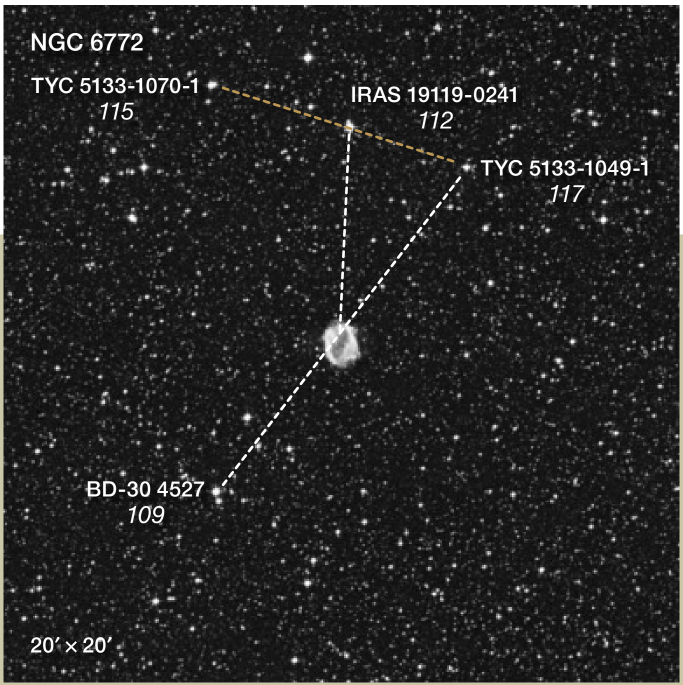
M 1-59: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; NGC 6765 PHOTO: STEFAN BINNEWIES / JOSEF POPSEL / CAPELLA OBSERVATORY; NGC 6765 FINDER IMAGE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY



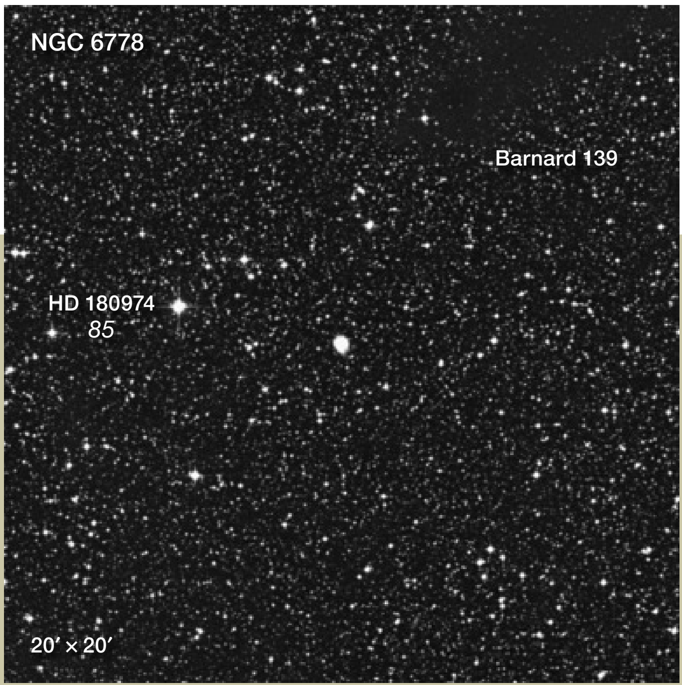
ety in my second survey with the 3½-inch telescope. It was a *full magnitude* dimmer than what I had recorded the limiting magnitude of the telescope in my first survey to be. Afterwards, I'd use NGC 6778 and other planetaries of its ilk to verify the limiting magnitude of the 3½-inch, and I still occasionally turn to the nebula as an observing bellwether. If I can hold it steady with the 3½-inch at 130× using the O III filter, then I consider the transparency to be better than average.

NGC 6778 is accompanied by an 8.5-magnitude star (HD 180974) some 4.9′ to the east-northeast. I'd like to think I may have detected Barnard 139, the dark nebula looming north-northwest — but I may need to return for another look.

Slew to a spot 6¾° almost due north of Delta Aquilae to arrive at the site of our next target, **Vy 2-2**. My 7-inch at 160× in a 17′ eyepiece field shows a small, inverted triangle of 10th- to 12th-magnitude stars.

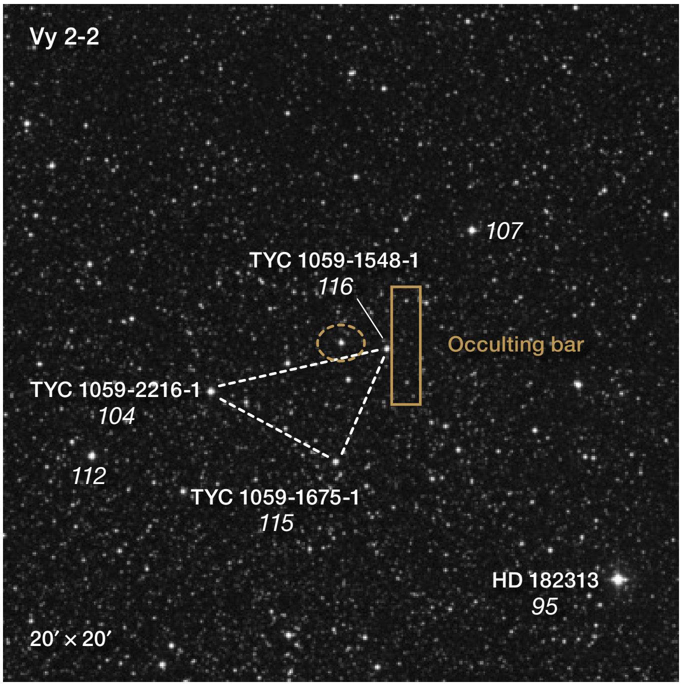


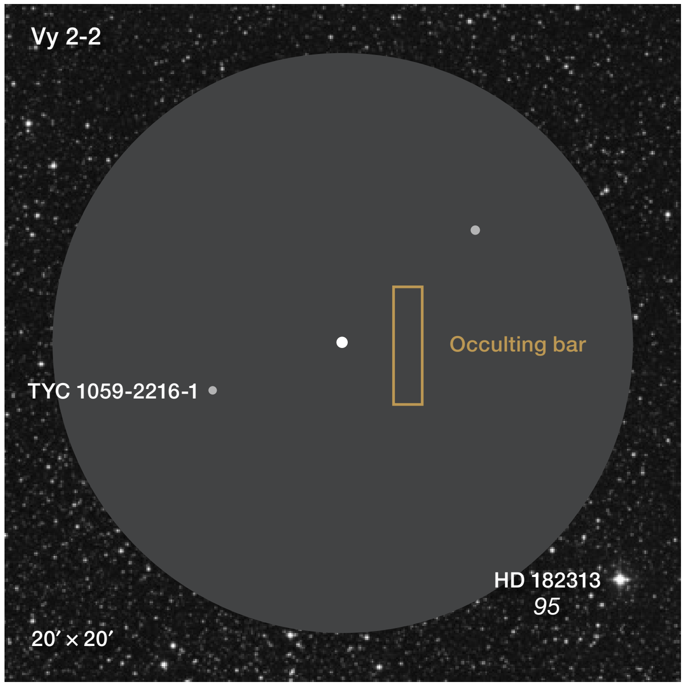
▲ **CELESTIAL INTERSECTIONS** To snag NGC 6772 you can avail yourself of several imaginary lines connecting stars as shown above. Moreover, a line dropped 6.4′ south from the 11.2-magnitude star at the center of the line of three stars intersects the longer imaginary line. These aids should guide you to your target.



▲ **BUTTERFLY SURPRISE** This finder image shows NGC 6778 to be an indistinct ovate shape, but applying multiple filters brings out the planetary nebula's pretty bowtie silhouette, as can be seen at top.

NGC 6772 PHOTO: GARY IMM; NGC 6772 FINDER IMAGE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; NGC 6778 PHOTO: GARY IMM; NGC 6778 FINDER IMAGE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY





▲ **FILTERS AND OCCULTING BARS** You may need extra equipment to snag some of the planetary nebulae discussed here, such as Vy 2-2. The use of an O III filter is necessary to reveal the planetary, and it might change the view in the eyepiece. For example, the 11.5-magnitude star at the southern vertex of the triangle shown at left disappeared with the filter as illustrated at right, while the westernmost "star" was, in fact, the planetary!

I examined the westernmost star of the triangle (11.6-magnitude TYC 1059-1548-1) with and without the O III filter. When I applied the filter, I noticed that the angle of the planetary appeared to change slightly with respect to the easternmost star (10.4-magnitude TYC 1059-2216-1). In addition, the westernmost object seemed to be closer to the eastern star of the triangle. Significantly, with the filter the 11.5-magnitude southern vertex star (TYC 1059-1675-1) disappeared, but when I removed the filter it popped back into view.

To better detect the planetary nebula, I maneuvered an occulting bar next to the westernmost star as a reference. Then, under a black drape (and still with the 7-inch at 160×) I "blinked" the field with the handheld O III filter by moving it back and forth in an east-west direction between my eye and the eyepiece. The image of the westernmost object seemingly moved east-northeast, away from the occulting bar, changing its angle and distance with respect to the easternmost star.

The filter had dimmed the images of the westernmost star, the southern vertex star, and all but a few of the field stars almost to extinction. Each time I applied the filter, it turned out that I'd been looking at the bluish, 14″-diameter, 12.7-magnitude Vy 2-2 (which had been masquerading as

Driveway Planetaries

Object	Designation	Constellation	Mag(v)	Size	RA	Dec.
NGC 6369	PK 2+5.1	Ophiuchus	11.4	38″	17^h 29.3^m	–23° 46′
M 1-59	PK 23-2.1	Scutum	12.5	5″	18^h 43.3^m	–09° 05′
NGC 6765	PK 62+9.1	Lyra	12.9	40″	19^h 11.1^m	+30° 33′
NGC 6772	PK 33-6.1	Aquila	12.7	86″	19^h 14.6^m	–02° 42′
NGC 6778	PK 34-6.1	Aquila	12.3	37″	19^h 18.4^m	–01° 36′
Vy 2-2	PK 45-2.1	Aquila	12.7	14″	19^h 24.4^m	+09° 54′
M 1-74	PK 52-4.1	Aquila	12.9	5″	19^h 42.3^m	+15° 09′
Hb 12	PK 111-2.1	Cassiopeia	11.9	16″	23^h 26.2^m	+58° 11′

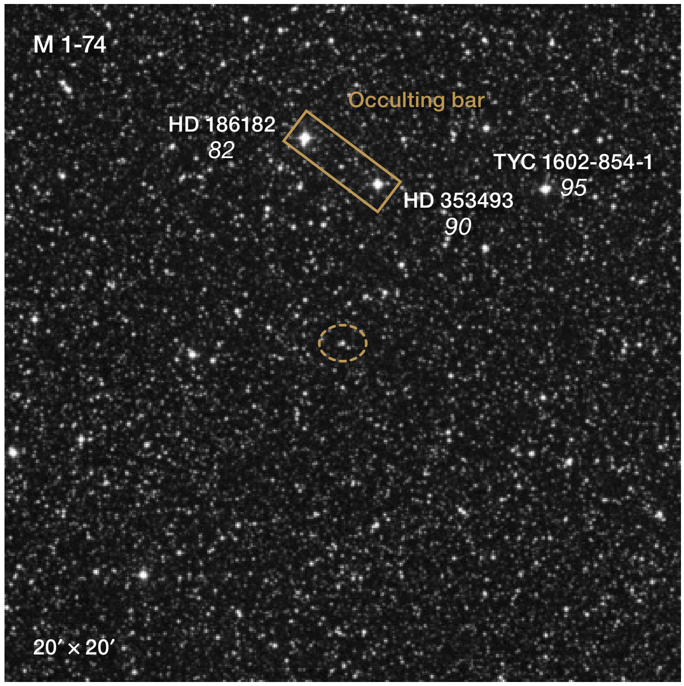
Angular sizes are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (2)

the westernmost star!) and the considerably dimmed easternmost star.

We'll need to go even farther north, almost to the border with Sagitta, to get to our last target in Aquila. In fact, find Beta (β) Sagittae and from there drop 2⅓° almost due south to find the general area of **M 1-74**. Three 8th- and 9th-magnitude foreground stars in the densely star-packed Aquila Milky Way form an obtuse triangle just 5′ north of the position of the tiny (5″ across) and dim (magnitude 12.9) planetary nebula.

To bag M 1-74 with my 7-inch Questar, I used an eyepiece equipped with the occulting bar plus an O III filter. I obscured the brightest of the three stars as well as the one next to it using the bar as shown at right. At 212×, I became aware of a bluish speck that danced in and out of averted vision. I centered the object, then switched to 424× and found that I could view it directly in the 6′ field as a fuzzy blue disk, appearing somewhat larger than stellar. The object disappeared when I removed the filter. I generally associate dim planetary nebulae with gray, so the blue color of M 1-74 surprised me.



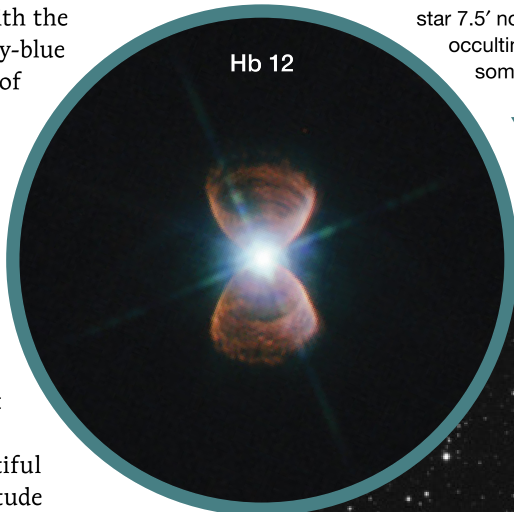
▲**HELPFUL GEOMETRIES** Again a triangle pinpoints our target. An 8.2-magnitude star, HD 186182, is 6.2′ north-northeast of the location of the planetary. Some 4.9′ to the north-northwest, 9.0-magnitude HD 353493 forms the southern vertex, and a 9.5-magnitude star 7.5′ northwest completes the triangle. I positioned an occulting bar as shown, which helped reveal the nebula some 5′ below.

Last But Not Least

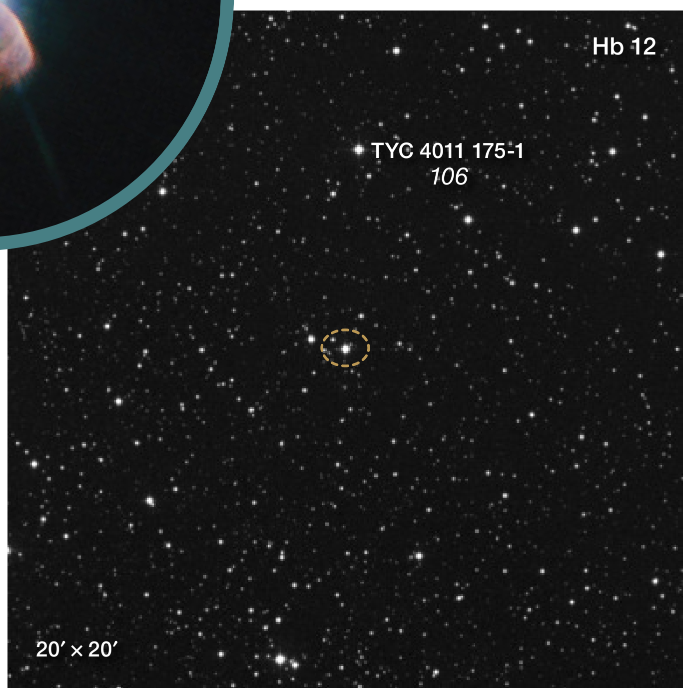
To get to our last target, **Hb 12**, start at Beta Cassiopeiae and slide some 5¾° west-southwest. My 7-inch at 160× (yielding a 17′ field) shows the 11.9-magnitude planetary to be not much more than a smudge. But with the O III filter, this nebula presents a steely-blue image with a brilliance seemingly out of proportion with its listed magnitude. When I increased the magnification to 318× (still using the filter), the object grew in size, became bluer, and its disk no longer appeared circular. I call it "that little planetary with an attitude" based on its response to the O III filter.

But wait, there's more! When the Hubble Space Telescope imaged it, that tiny 6″-diameter "planetary with an attitude" metamorphosed into a beautiful hollow hourglass. And its 14th-magnitude central star is likely a close binary with a short orbital period suspected of playing a role in the shaping of the hourglass.

What a beautiful grace note on which to end this brief survey. There's a certain satisfaction derived from working at the limit of equipment under adverse conditions, and pushing the performance envelope of a telescope is no exception. I feel that if I doubled the aperture of my telescope, I would simply find myself writing similar words about a different, even dimmer set of planetary nebulae.



▼**HEAVENLY HOURGLASS** The Hubble Space Telescope unveiled Hb 12's ethereal butterfly shape (the image at left is about 0.5′ across). While your scope may not reveal the same detail, bear this image in mind as you observe.



■ Texas-based **DON FERGUSON** will be 88 years old this August, but he, his family, and his telescope are planning to be right on the centerline of the total solar eclipse in April 2024.

M 1-74 FINDER IMAGE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; HB 12 PHOTO: NASA / ESA; HB 12 FINDER IMAGE: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

See anything amiss in this century-old excerpt from the July 1923 issue of *Sky & Telescope?*

As many of us finish work on our farms, dusk summons a stellar ruby to the southern sky: beautiful Antares, the ruddy heart of Scorpius, shining over fields and farmhouses. A red giant, Antares is young, a large cool star that has recently emerged from the frigid depths of space. When you gaze at this brilliant red star, you're seeing our own Sun as it looked long ago, shortly after its birth.

Three problems: First, this magazine didn't actually exist until 1941; the excerpt is fictitious even though it reflects the thinking of the time. Second, astronomers now classify Antares not as a red giant but as a red *supergiant*, a word that didn't enter the English language until 1925. Third — and worst — Antares is no stellar infant. Instead, it's an enormous red star in the final phase of its life and could even go supernova tonight.

How did astronomers 100 years ago get the direction of stellar evolution so wrong?

When Red Giants Were Young

One hundred years ago astronomers thought large, cool stars were destined to become stars like the Sun.

▲ **VV CEPHEI** Material from a red supergiant (right) spirals toward its blue partner (left), as depicted in this dramatic painting by Bob Eggleton. A century ago, many astronomers thought that red giants and supergiants were the youngest stars.

The Discovery of Giant Stars

Before anyone could think that red giants and supergiants were young, someone had to first recognize their existence. That didn't happen until the start of the 20th century.

It all began with Danish astronomer Ejnar Hertzsprung. He was examining stars that Harvard astronomers had sorted into different spectral types with the now-familiar *O B A F G K M* system. These spectral types correlate with both a star's surface temperature and its color. The hot *O* and *B* stars are blue; warm *A* and *F* stars are white or yellow-white; yellow stars, like the Sun, are spectral type *G*; and the cool *K* and *M* stars are orange and red.

To classify the spectral types of countless stars, Harvard College Observatory director Edward Pickering hired women who, with one exception, had no previous scientific background, nor did any experience seem necessary to simply

examine stellar spectra. But the one exception, Antonia Maury, paved the way for Hertzsprung to arrive at a profound discovery. Maury used lowercase letters to denote the widths of a star's spectral lines. In particular, she labeled stars with narrow spectral lines type c. Pickering didn't care for what he saw as needless complexities and didn't adopt her system. He suspected the line widths were instrumental defects that indicated nothing about the stars themselves.

But Hertzsprung discovered otherwise. He noticed that Maury's c-stars tended to have small *proper motions*. A star's proper motion is its year-after-year apparent movement against the stellar background, measured in fractions of a degree per year or century. In general, the farther a star is from us, the smaller its proper motion — just as distant mountains appear nearly stationary as you drive down the highway, but road signs in the foreground whiz by. From the small proper motions of the c-stars, Hertzsprung correctly deduced that they were distant. To look so bright from so far away, they must emit profuse amounts of light — much more than the Sun.

In 1906 Hertzsprung wrote Pickering a letter, reporting that yellow, orange, and red stars come in two types: bright and dim. Hertzsprung mentioned four pairs of stars with similar spectral types but large luminosity differences. His first pair was Capella and Alpha Centauri A. Both stars are yellow and spectral type *G*, but Capella is dozens of times more luminous. He also cited the orange *K* stars Arcturus and 70 Ophiuchi and noted that the former greatly outshines the latter. The same pattern holds for the *K* stars Aldebaran and 61 Cygni. His final pair was brilliant Betelgeuse and Lalande 21258, a dim star in Ursa Major, both red stars of spectral type *M*. Whereas Betelgeuse is bright but distant, which means it's very luminous, Lalande 21258 is nearby yet too faint to be seen with the naked eye, a clear sign its light is feeble.

▲ **DYNAMIC DUO** German astronomer Karl Schwarzschild (left) coined the term "giants" for the stars that Danish astronomer Ejnar Hertzsprung (right) had deduced were large and luminous.

Alas, Hertzsprung published his initial discoveries — in 1905 and 1907 — in a German photography journal, *Zeitschrift für wissenschaftliche Photographie*. Most astronomers therefore never heard of Hertzsprung's work. "One of the sins of your youth was to publish important papers in inaccessible places," British astronomer Arthur Eddington later wrote.

Meanwhile, a young Princeton astronomer was discovering the same startling pattern. Henry Norris Russell had gotten into astronomy as a child: "I recall my parents showing me the transit of Venus in 1882, when I was five years old." Russell determined the distances of numerous stars by painstakingly measuring each one's *parallax*, the tiny apparent shift the star shows because we view it from slightly different vantage points as Earth circles the Sun. Once he knew a star's distance, he could use its apparent brightness to calculate its *luminosity*, that is, how much light it emits into space.

The coolest stars come in two types, he said. As Russell put it during a 1913 talk in England, reported in the British journal *The Observatory*, " . . . among the reddest stars (K and M) there is a distinct separation into two groups. There seem to be no stars of Class M which are closely comparable with the Sun in brightness — they are either much brighter or much fainter."

Furthermore, both Hertzsprung and Russell deduced that luminous red stars like Antares and Betelgeuse had to be enormous. Because red stars are cool, their surfaces radiate only a tiny amount of light per square inch. For example, a star with half the Sun's temperature, as measured in Kelvin, emits only 1⁄16 as much light per square inch.

For a cool, red star to give off so much light, the star's surface must have a gargantuan number of square inches. In other words, the star is *huge* — so huge that German astronomer Karl Schwarzschild, who thought highly of Hertzsprung's work, named them "giants" ("Giganten") during a 1908 lecture and used the word in print the following year. Thus were giant stars christened. They were much rarer than the more compact stars that Russell started calling "dwarfs" in 1910.

Red Giants as Stellar Youngsters

Although both Hertzsprung and Russell recognized the existence of red giants, it was Russell who explored the implications for the lives of stars. "He was really pre-occupied with

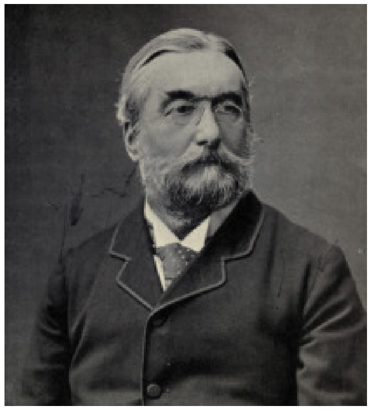
SHIM HARNO / ALAMY STOCK PHOTO

how stars evolve," says David DeVorkin (National Air and Space Museum), author of *Henry Norris Russell: Dean of American Astronomers*. "Russell took an evolutionary interpretation, whereas Hertzsprung did not want to make a claim."

In the late 1800s, the prevailing view was that stars started off hot and then cooled down as they radiated their light away. They therefore proceeded from blue to yellow to red. Even today astronomers refer to hot and cool stars with the anachronistic terms "early-type" and "late-type," respectively.

There was a dissenting voice, however: English astronomer J. Norman Lockyer. In 1868 he had spectroscopically detected a new chemical element on the Sun that he named helium. A year later he founded *Nature*, which began as a popular science magazine but soon became a scientific journal. Lockyer thought a star originated as a cool swarm of meteoritic particles, which collided with one another and heated up, while gravity caused the swarm to contract. Then, after reaching a peak temperature, the star cooled off again.

Russell revived this discredited cool-to-hot-to-cool scenario, though he thought stars consist of gas, not meteoritic particles. In Russell's view, a young star's gravitational pull compressed its gas, which by the laws of physics heated up, making the star turn from red to yellow to blue.



◀ **FORCE OF NATURE** English astronomer Norman Lockyer created the journal *Nature* and served as its editor for half a century. Late in life he was delighted when his theory of stellar evolution received support from Henry Norris Russell.

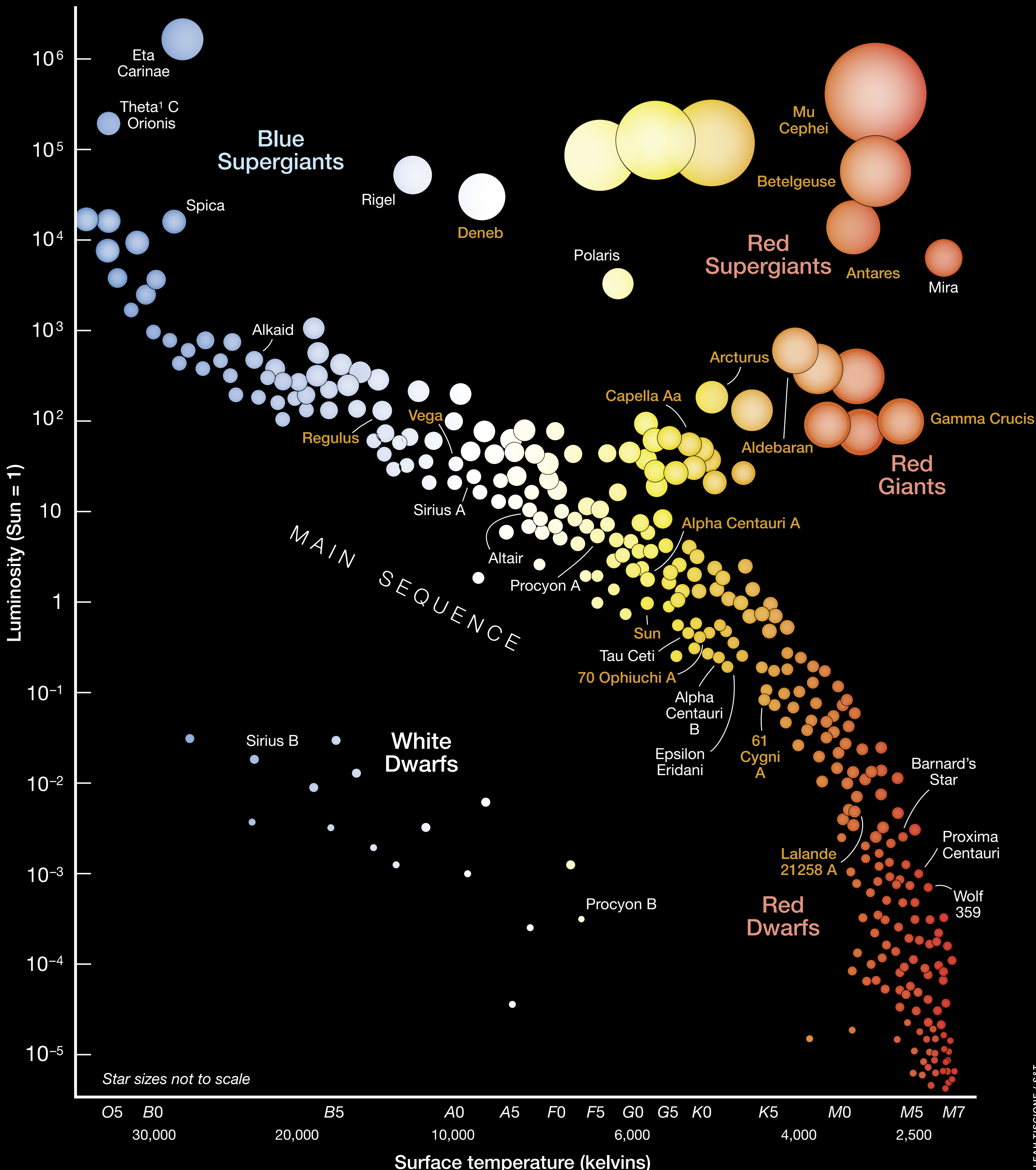
During his 1913 lecture Russell said, "As almost everybody will agree that a star contracts as it grows older, this leads us to suppose that the giant stars of Class M represent a very early stage of evolution, the other giant stars later stages according to whiteness . . ." Thus, Antares and Betelgeuse were — in Russell's opinion — stellar newborns. Russell proposed that a star begins life as a large, diffuse *M*-type giant. He said gravity then compresses the star and heats it up, making it a *K*-type giant like Arcturus. The star then shrinks further, becoming a yellow *G*-type giant like Capella, until eventually it shines as a hot blue giant. During its red-to-blue giant transition, the star's luminosity holds steady: Even though the surface is heating up, the diameter is decreasing, so the two effects cancel each other out.

As Russell noted, when a star shrinks enough to become hot and blue, it gets so dense that the *ideal gas law* — which says the gas obeys simple relations among temperature, pressure, and volume — starts to break down. As a result, the star has a harder time shrinking further, which means gravita-

RIVAL OF MARS — AND BETELGEUSE Marking the heart of Scorpius, Antares is a conspicuous sight on July evenings as it crosses the meridian due south. In this striking photo, the star appears above Mount Custer in Glacier National Park, Montana. Antares is normally the second brightest red supergiant in the sky, behind Orion's brilliant Betelgeuse, though both stars vary in brightness.

LOCKYER: *NOTABLES OF BRITAIN: AN ALBUM OF PORTRAITS AND AUTOGRAPHS OF THE MOST EMINENT SUBJECTS OF HER MAJESTY IN THE 60TH YEAR OF HER REIGN* / WIKIMEDIA COMMONS / PUBLIC DOMAIN; ANTARES / SCORPIUS: ALAN DYER

HERTZSPRUNG-RUSSELL DIAGRAM Developed independently by Ejnar Hertzsprung and Henry Norris Russell, this graph plots stellar luminosity against stellar color. A century ago, stars were thought to begin life as red giants (upper right of diagram). They then heated up, tracking leftward on the diagram, until they became hot and blue, after which they cooled and faded along what we now call the main sequence, the diagonal series plotted from top left to lower right.



LEAH TISCIONE / S&T

tional contraction no longer raises its temperature so easily. But the star is still radiating light away, causing the star to cool. It gets smaller, and its light begins to fade. On the Hertzsprung-Russell diagram, the star moves down the diagonal line that marks the dwarf sequence — from bright and blue to faint and red. In this way, once-brilliant red giants end their luminous lives as humble red dwarfs, "stars in a late stage of evolution, past their prime, and in some cases verging toward extinction," he wrote in a 1910 *Astronomical Journal* article.

The son of a Presbyterian minister, Russell preached this theory during a long train trip that carried dozens of astronomers from Boston to California. As Canadian astronomer John Stanley Plaskett recalled:

> *I will never forget the trip . . . in 1910, how hot it was through the desert, what a fine time we had at the Grand Canyon and particularly how Henry Norris Russell worked so hard to persuade his fellow astronomers, what a conservative bunch they were, that the course of stellar evolution had an ascending as well as a descending branch. What a beautiful and satisfactory theory that was . . .*

The long-serving editor of *Nature* was elated by these developments. Lockyer wrote to the 32-year-old Russell: "I have had to wait some years for such a clear cut support of my views & am delighted that it is afforded by researches of a different order from my own."

The Sudden Death of a Theory

Lockyer died in 1920, and four years later Russell's theory ran into trouble. In 1924 Eddington found a correlation between a star's mass and its luminosity — which fellow British astronomer Harold Jeffreys, writing in *Nature*, called "the sudden death of the giant and dwarf theory."

Here's why. If the Sun was once a blue dwarf, it should have had the same mass then as it does now. But Eddington's relation indicated otherwise. In particular, he found that dwarf stars of different colors have different masses: Blue dwarfs are more massive than yellow dwarfs, which in turn are more massive than red dwarfs.

The theory also had a conceptual problem. Russell had assumed that atoms in a star's gaseous interior resemble those in the air, each with a full complement of electrons surrounding its nucleus. "But the atoms in a star are very much smaller than ordinary atoms," Eddington wrote in a 1924 paper published in the *Monthly Notices of the Royal Astronomical Society*. "Several layers of electrons have been stripped away, and the gas-laws ought therefore to hold up to far greater densities." Thus, even as a star grew denser and denser, its interior should still behave as a perfect gas, because of what Eddington called "the mutilated stellar atoms" that resulted from the star's torrid temperature. Russell had said that the breakdown of the ideal gas law caused a star's temperature to plateau and then decline, so Eddington's claim meant there was no physical reason for the star to stop heating up and start cooling down.

Despite the setback, Russell tried to persevere. In a 1925 *Nature* paper, he even resorted to the still-familiar tactic of quoting Mark Twain that rumors of his theory's demise had been "greatly exaggerated."

Eddington himself suggested a way out. Perhaps stars slowly consume their mass as they age. He proposed that protons, which are positively charged, hit electrons, which are negatively charged, and annihilate each other, generating energy. Thus, as a blue dwarf ages and becomes yellow and then red, it loses mass, explaining why red dwarfs have little mass. This was a slow process, though, so for it to work, the universe had to be trillions of years old. But in 1929, Edwin Hubble's discovery of the universe's expansion suggested its age was only in the billions of years.

Summing up the confusion, University of Michigan astronomer Dean McLaughlin wrote in *Publications of the Astronomical Society of the Pacific*, "For several years I have told students that I knew all about stellar evolution in 1923, less

ALAN DYER

▲ **SOUTHERN GEM** Located 89 light-years from Earth, Gamma Crucis is the nearest *M*-type red giant of all. Gamma tops the Southern Cross, and its ruddy color contrasts vividly with the three blue *B* stars that comprise the rest of the constellation's iconic form.

in 1925, and nothing at all since 1930."

By then, however, Russell had moved on to other matters. Not until the early 1950s did astronomers recognize how stars truly evolve: Sunlike stars become red giants, not the other way around.

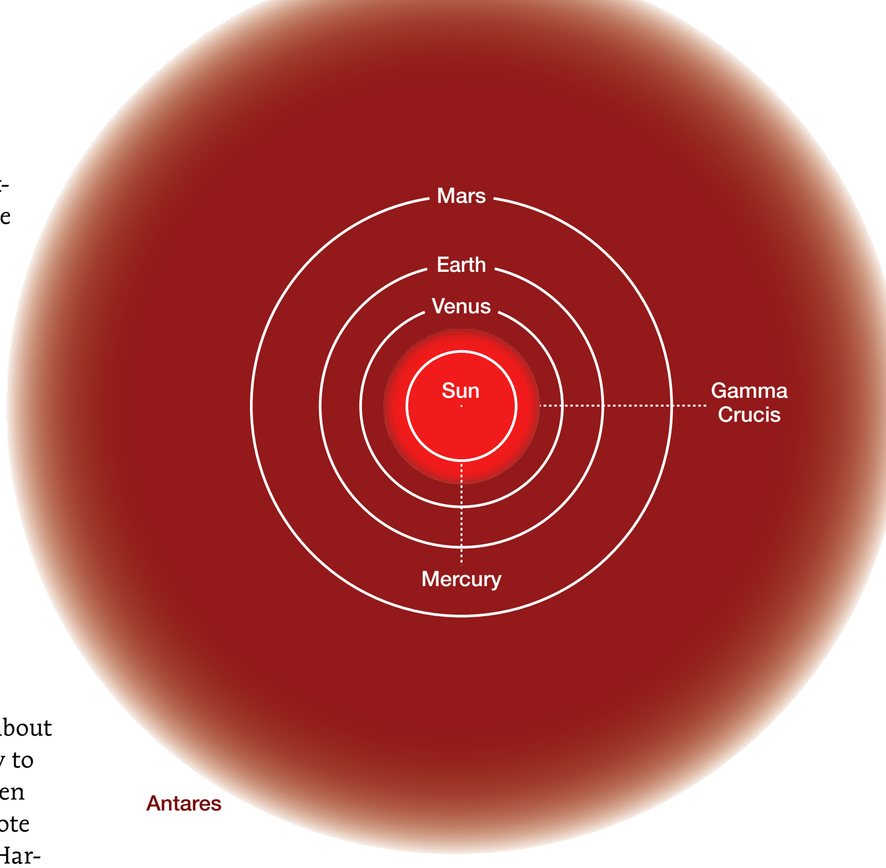
The Modern View

In retrospect, any theory of stellar evolution from the 1910s was doomed because astronomers were ignorant of two basic facts: what stars are made of and what powers them. At that time astronomers thought stars consisted of iron, silicon, and the other heavy elements that constitute the Earth, and the easiest power source for astronomers to envision was the familiar force of gravity. We now know that most stars are made mostly of hydrogen, the lightest and simplest element, and shine via nuclear reactions that convert hydrogen into helium.

Today, not only do astronomers have different ideas about how stars evolve, but they also use different terminology to describe them. For one thing, we now distinguish between giants and supergiants. The first to use "super-giant" (note the hyphen) appears to have been Harvard astronomer Harlow Shapley, who had been a graduate student of Russell's a decade before. In early 1925 Shapley employed the term to describe stars such as Antares and Betelgeuse. That's also how his graduate student, Cecilia Payne, referred to Betelgeuse and Deneb in her PhD thesis that year. So if you're still calling Antares and Betelgeuse "red giants," you're a century behind the times. Indeed, it's like calling a whale a dolphin. Whereas a red giant is about 100 times more luminous than the Sun, a red supergiant is about 100 times brighter than that. Both Antares and Betelgeuse outshine the Sun more than 10,000 times, emitting more light in a single hour than the Sun does all year.

If we replace the Sun with the largest red *supergiants*, such as Mu Cephei or VV Cephei, our new home star would engulf Mercury, Venus, Earth, Mars, the asteroid belt, Jupiter, and perhaps Saturn, whereas the nearest *M*-type red giant, Gamma Crucis in the Southern Cross, wouldn't even touch Venus. Moreover, most red supergiants die violently, by exploding. In contrast, red giants die gently, by casting off their outer layers and exposing their hot cores, which are white-dwarfs-to-be (*S&T:* Dec. 2022, p. 28).

Another new term appeared in the 1920s when astronomers began calling the series of dwarf stars the *main sequence*. Today, *K* and *M* main-sequence stars are still called orange and red dwarfs, since they are indeed small and faint. But using "dwarf" for hotter main-sequence stars — such as *B*-type Regulus, *A*-type Vega, and the *G*-type Sun — is problematic because it incorrectly implies that these stars are insignificant. Regulus, for example, emits more light than any other star within 80 light-years of Earth aside from Aldebaran. Even our more modest Sun outshines 95% of all other stars.



▲ **X-TRA LARGE** Red supergiants like Antares are much larger and more luminous than mere red giants like Gamma Crucis. If placed in our solar system, the outer atmosphere of Antares would swallow up the inner solar system and extend well beyond the orbit of Mars.

TERRI DUBÉ / *S&T*

As we know today, every main-sequence star — hot or cool, bright or dim, great or small — is powered by nuclear reactions in its core that convert hydrogen into helium. About 6 billion years from now, the Sun's core will run out of hydrogen. Our star will then begin burning hydrogen in a layer around its helium-filled core, causing the Sun to expand. It will first become a *subgiant*, a term Mount Wilson astronomer Gustaf Strömberg coined in 1930, and then a red giant. After igniting its helium, the Sun will ultimately shed its atmosphere and evolve into a white dwarf.

The few stars born more than eight times as massive as the Sun usually expand into red supergiants late in life, then explode as supernovae. However, the most massive stars blow off their outer atmospheres and stay hot and blue, turning into Wolf-Rayet stars instead (*S&T:* Feb. 2023, p. 12). They, too, may end their lives as supernovae, or they may collapse into black holes without exploding.

Although supergiants outweigh the Sun, they are so distended that the gas densities in their atmospheres are low. This is what makes their spectral lines sharp and narrow, the very feature that Antonia Maury intuited might be important and that led Ejnar Hertzsprung to his discovery of these large and luminous objects. They are stars not in the first flush of life but instead on the brink of death.

■ **KEN CROSWELL** is an astronomer who earned his PhD from Harvard University for studying the Milky Way. He is also the author of *The Alchemy of the Heavens* and *The Lives of Stars*.

OBSERVING
July 2023

1 DUSK: Face west to see Venus and Mars about 3½° apart. Follow them as they sink toward the horizon in deepening twilight. (See page 46 for more on this and other events listed here.)

6 EARTH is at aphelion, farthest from the Sun for the year (some 3.4% farther than it was at perihelion in January).

6 EVENING: The waning gibbous Moon rises in the east-southeast in tandem with Saturn; around 3° separates the pair.

9 DUSK: Mars and Regulus, Leo's brightest star, shine above the western horizon with less than 1° between them. Venus blazes about 4½° lower right of the pair.

11 MORNING: Look toward the east to see the waning crescent Moon lead Jupiter above the horizon. The gap between them starts at 6° and shrinks somewhat as they climb higher.

12 MORNING: In a reversal of the previous morning's scenario, now the Moon trails Jupiter as they rise in the east; again around 6° separates them.

13 MORNING: The thin lunar crescent pops above the horizon in the east-northeast with the Pleiades some 2° above.

19 DUSK: The extremely thin lunar sliver, Mars, Venus, and Mercury form a rhomboid low on the western horizon. Leo's Regulus is part of the fray.

20 DUSK: The waxing crescent Moon, Venus, and Mars form a triangle near Regulus. Look toward the west after sunset.

22 DUSK: Still in the west, Mars, Venus, and Mercury arc around Regulus from the upper left to the lower right of the star.

24 EVENING: Face west-southwest to see the nearly first-quarter Moon and Spica sink toward the horizon with some 2° between them.

28 DUSK: Mercury comes to within 10′ of Regulus low in the west. Binoculars will enhance the sight.

28 EVENING: The waxing gibbous Moon is in the south-southwest where it gleams in Scorpius, about 5° left of Antares.

30 MORNING: The Southern Delta Aquariid meteor shower peaks. The Moon sets in the wee hours of the morning, after which viewing conditions improve.
— DIANA HANNIKAINEN

▲ Summer nights can be very short (or non-existent) for stargazers at northerly latitudes, but dark nights are just around the corner. While waiting for them, northern skies might offer other delights, such as these noctilucent clouds seen near Vallentuna in Sweden.
P-M HEDÉN

JULY 2023 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart

Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.
NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

FULL MOON
July 3
11:39 UT

LAST QUARTER
July 10
01:48 UT

NEW MOON
July 17
18:32 UT

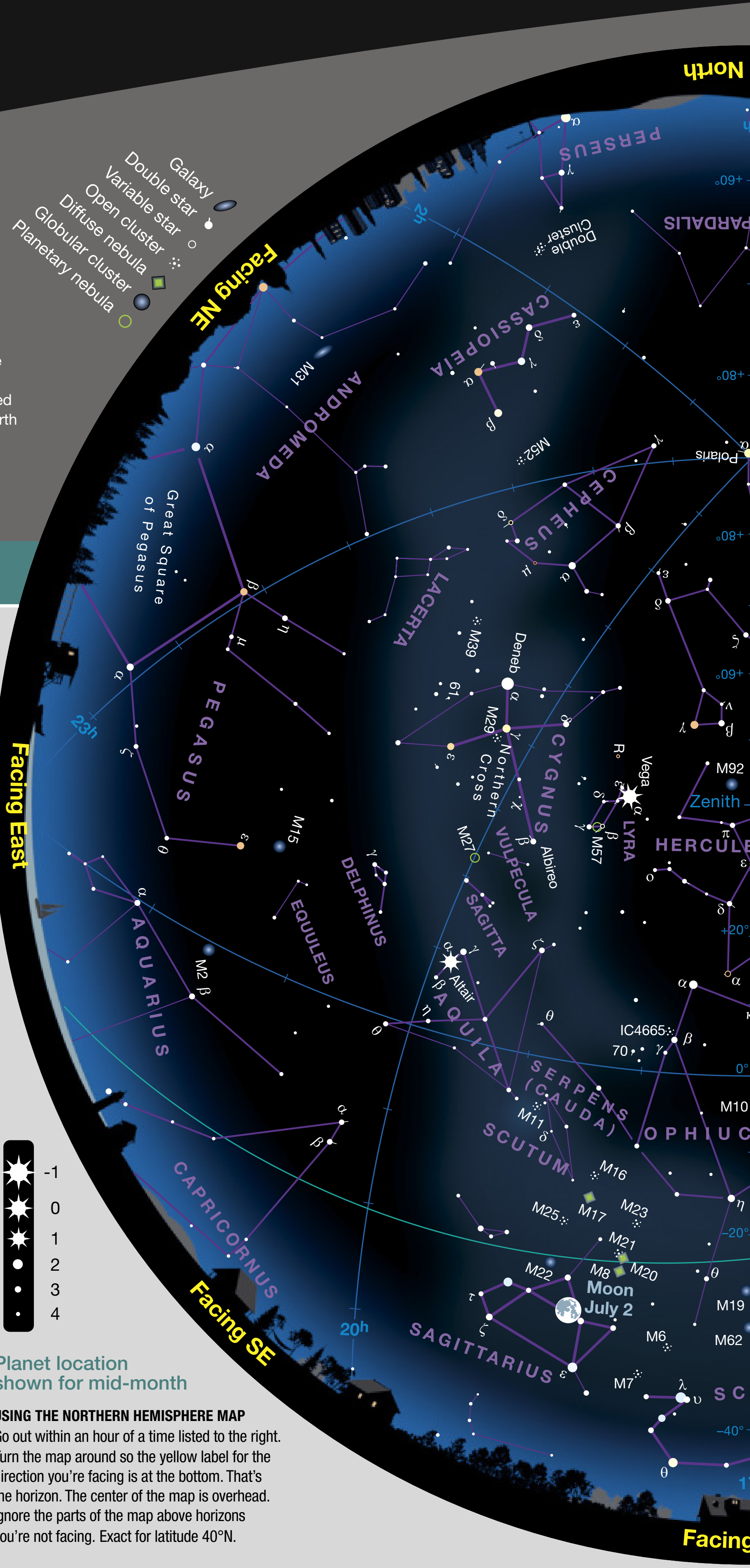
FIRST QUARTER
July 25
22:07 UT

DISTANCES

Perigee	July 4, 22^h UT
360,152 km	Diameter 33′ 11″
Apogee	July 20, 07^h UT
406,288 km	Diameter 29′ 25″

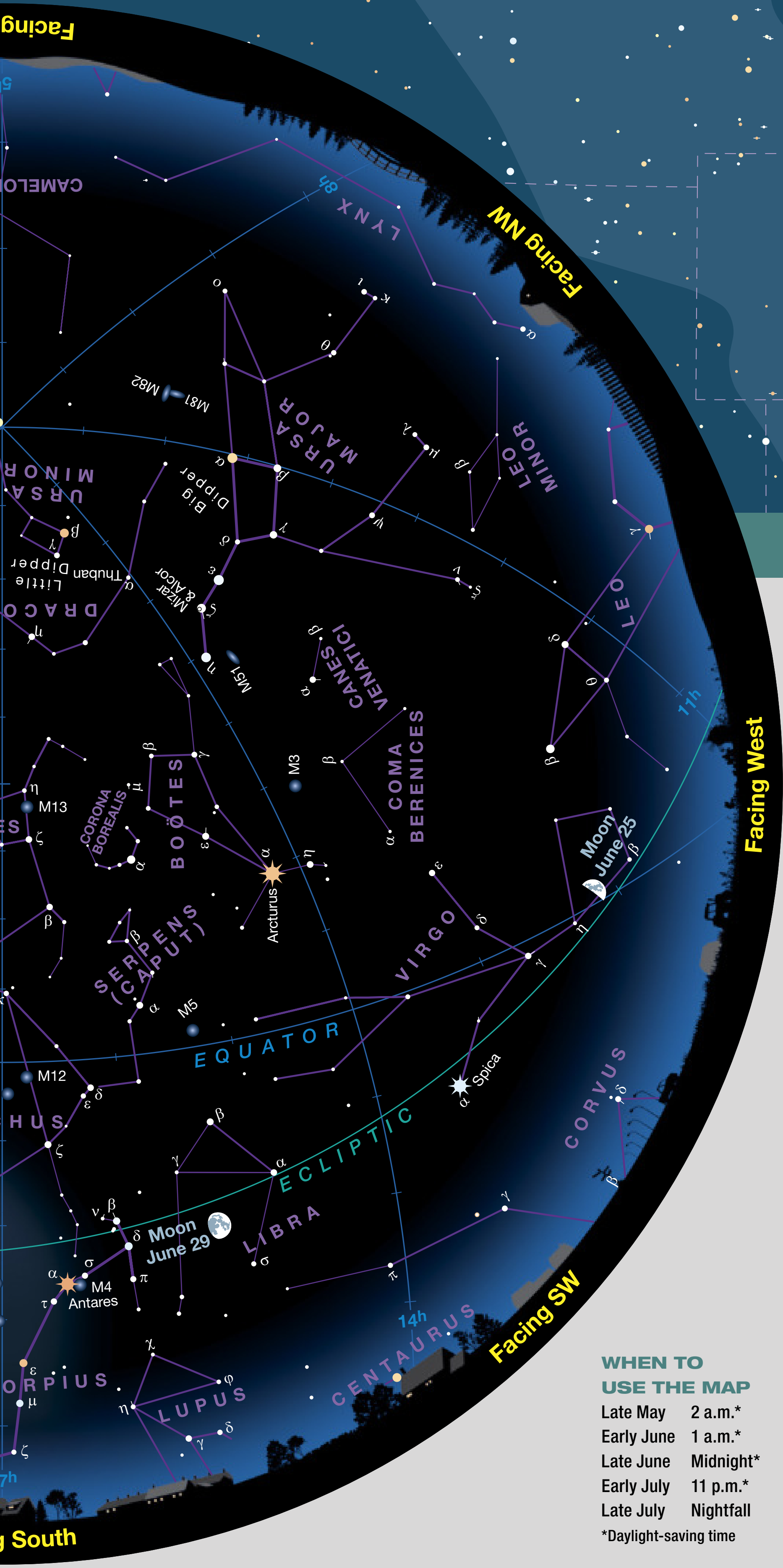
FAVORABLE LIBRATIONS

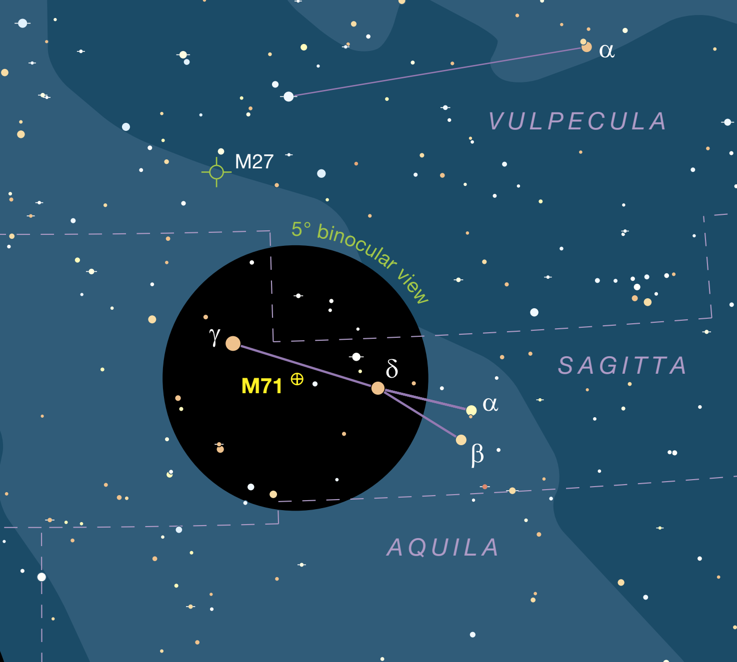
• Volta Crater	July 3
• Brianchon Crater	July 4
• Byrd Crater	July 5



Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP
Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





Binocular Highlight by Mathew Wedel

My Old Enemy

Our target this month is **M71**, an 8.4-magnitude globular cluster in Sagitta, the Arrow, hanging halfway between Delta (δ) and Gamma (γ) Sagittae. More than any other celestial object, M71 taught me how to observe. Early on, I struggled to find the cluster at all, despite using a 6-inch reflector. Now I check in on it regularly — and more often than not, I'm only using binoculars. So, what changed?

In the old days I'd haul out the scope, paying minimal attention to local conditions or where things were situated in the sky, then start running up the magnification. That was exactly the wrong strategy for M71. The cluster is so loosely aggregated that for a long time astronomers suspected it to be a dense open cluster rather than a globular. To make matters worse, M71 sits in a dense stretch of the Milky Way. High magnification restricts the field of view so much that the cluster starts to blend into the rich galactic background, especially in poor skies.

Gradually I learned to approach M71 as a hunter: humbly and deliberately. Now, I wait for clear skies and for the cluster to *culminate* — so it's as high in the sky as possible. I cultivate my dark adaptation and avoid local light pollution. And I use clean, clear optics at low power. Even then, M71 is still a challenge for me in 7×50 binoculars. With 10×50s it's more straightforward, though it remains a faint ball of fluff. Bigger binos will reel it in easily most nights, pulling down starlight that has been traveling for 13,000 years, since the end of the most recent Ice Age.

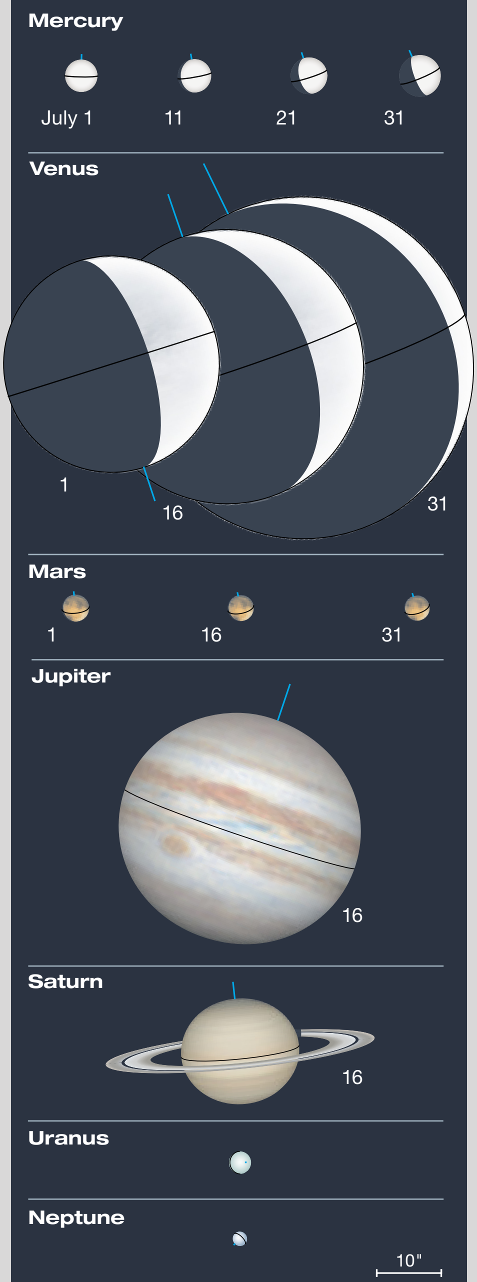
I visit M71 frequently, not just to see how it's doing, but also to see how I'm doing as an observer. It's the stone that keeps me sharp.

■ **MATT WEDEL**'s biggest observing debacle was focusing on what he thought was Saturn . . . on its final approach to LAX.

WHEN TO USE THE MAP

Late May	2 a.m.*
Early June	1 a.m.*
Late June	Midnight*
Early July	11 p.m.*
Late July	Nightfall

*Daylight-saving time



PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk starting on the 14th • **Venus** visible at dusk to the 30th • **Mars** visible at dusk and sets in the late evening • **Jupiter** visible at dawn all month • **Saturn** rises in the late evening and visible to sunrise.

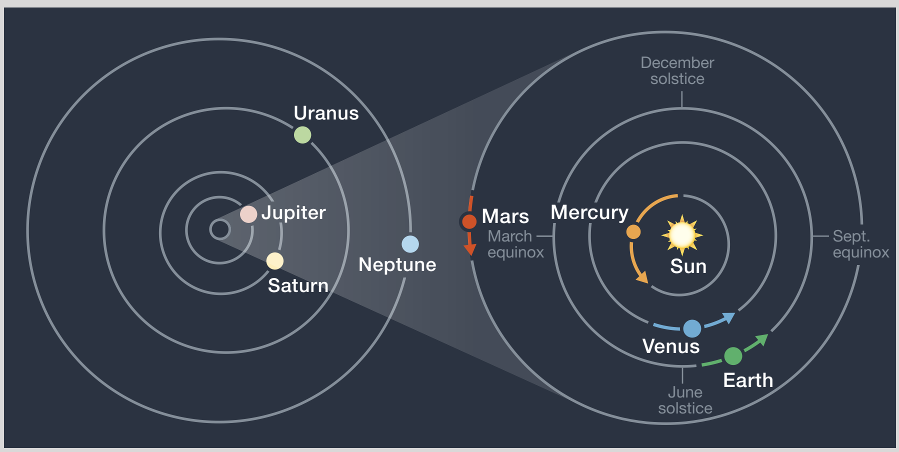
July Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	6^h 37.5^m	+23° 09′	—	–26.8	31′ 28″	—	1.017
	31	8^h 38.6^m	+18° 27′	—	–26.8	31′ 31″	—	1.015
Mercury	1	6^h 36.7^m	+24° 25′	1° Mo	–2.3	5.1″	100%	1.326
	11	8^h 07.6^m	+22° 06′	11° Ev	–1.1	5.2″	91%	1.288
	21	9^h 21.6^m	+16° 51′	20° Ev	–0.4	5.7″	77%	1.175
	31	10^h 18.3^m	+10° 37′	25° Ev	0.0	6.5″	63%	1.038
Venus	1	9^h 32.0^m	+15° 06′	42° Ev	–4.7	33.4″	32%	0.499
	11	9^h 50.4^m	+11° 56′	38° Ev	–4.7	39.1″	24%	0.426
	21	9^h 57.2^m	+9° 15′	31° Ev	–4.6	45.9″	15%	0.363
	31	9^h 49.7^m	+7° 32′	20° Ev	–4.4	52.9″	6%	0.315
Mars	1	9^h 46.7^m	+14° 40′	45° Ev	+1.7	4.2″	95%	2.210
	16	10^h 21.5^m	+11° 23′	40° Ev	+1.8	4.1″	96%	2.297
	31	10^h 56.1^m	+7° 49′	35° Ev	+1.8	3.9″	97%	2.372
Jupiter	1	2^h 27.8^m	+13° 24′	60° Mo	–2.2	36.5″	99%	5.394
	31	2^h 44.7^m	+14° 39′	84° Mo	–2.4	39.7″	99%	4.964
Saturn	1	22^h 36.4^m	–10° 33′	122° Mo	+0.8	18.0″	100%	9.214
	31	22^h 31.6^m	–11° 07′	152° Mo	+0.6	18.7″	100%	8.874
Uranus	16	3^h 18.5^m	+17° 57′	61° Mo	+5.8	3.5″	100%	20.113
Neptune	16	23^h 52.1^m	–2° 13′	116° Mo	+7.9	2.3″	100%	29.454

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.

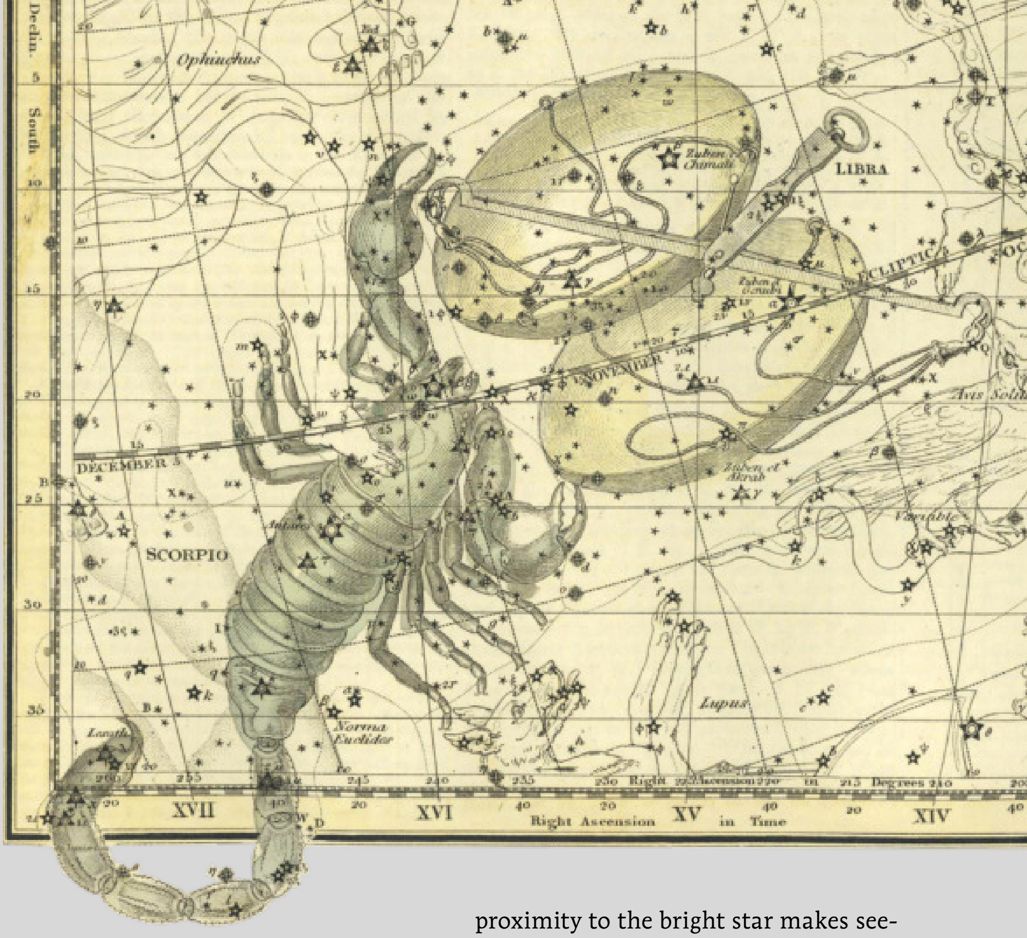
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during July. The outer planets don't change position enough in a month to notice at this scale.



Summer's Scorpion

Visit one of the most striking zodiacal constellations.



▲ **SCORPION AND SCALES** Although this chart from Alexander Jamieson's 1822 *Celestial Atlas* depicts both Scorpius and Libra, there was a time when the Scorpion alone occupied this swath of sky — the stars of Libra formed the creature's outstretched claws.

ALEXANDER JAMIESON / *CELESTIAL ATLAS* (1822) / UNITED STATES NAVAL OBSERVATORY LIBRARY / PUBLIC DOMAIN

Which Scorpius will you see tonight?

Of course, there's only one Scorpius, the Scorpion, but it presents several different appearances. It's well known as a magnificent constellation with its heart afire with red supergiant Antares, and its long double-twisted length marked with numerous bright stars. But how much of the celestial Scorpion you see depends on how high it rises in your sky.

The fishhook pattern of Scorpius encompasses a vast, north-to-south swath of the celestial sphere. Its main stars are arrayed from a declination of about –20° all the way down to –43°. For observers at the populous latitude of 40° north, the constellation's stars climb to altitudes ranging from 30° above the horizon to as low as 7°. On a clear night the dimming from atmospheric extinction at 30° is slight, but at 10° or less it's significant and can make the most southerly stars in the Scorpion difficult to see. And for the many observers in Canada, Great Britain, Ireland, and northern Europe, much of Scorpius never rises at all. Imagine that — a large piece of a major zodiacal constellation is out of sight for a sizable percentage of the world's population.

So far, we've been discussing how the Scorpion's appearance changes with latitude, but there's another alteration that has occurred over time. Scorpius once extended all the way west to Virgo. It was the Romans who robbed the Scorpion of its outstretched claws to create a new zodiacal constellation: Libra, the Scales. That's why the two brightest stars in Libra — Alpha (α) and Beta (β) Librae — are known as Zubenelgenubi and Zubeneschamali, names that mean "the southern claw" and "the northern claw," respectively. If you look at the region on a clear summer night, you should be able to trace the stars delineating the Scorpion's clipped claws.

Among the versions of Scorpius that we can (or can't) see, let's focus on the northern half of the constellation. Our attention is immediately drawn to Antares, the aforementioned red heart of Scorpius. It's listed as magnitude +0.9, though the star is slightly variable. Antares is flanked by a pair of stars that are of nearly identical brightnesses: 2.9-magnitude Sigma (σ) Scorpii and 2.8-magnitude Tau (τ) Scorpii.

In addition, this region offers two fine Messier globular star clusters: M4 and M80. Of the two, M4 is by far the more impressive. At a distance of around 7,200 light-years, it's the closest bright globular cluster to Earth. Situated less than $1\frac{1}{3}$° west of Antares, M4 is easy to locate. Unfortunately, its proximity to the bright star makes seeing this magnitude-5.4 cluster with the naked eye very difficult. With binoculars, however, it's an easy catch.

What about the head of the Scorpion? It's best known for several fascinating telescopic double stars, but naked-eye observers can enjoy the gentle north-south curve of Beta, Delta (δ), and Pi (π) Scorpii, accompanied by a few nearby dimmer stars. Together they form a kind of gate through which the Moon and planets pass as they travel along the ecliptic, which cuts across the constellation just south of 2.5-magnitude Beta — the most northerly star in the gate.

Lastly, be sure to look in on the mysterious Delta Scorpii (also known as Dschubba). The star hovered at magnitude 2.3 until the year 2000, when it started to brighten. Delta eventually reached a peak of magnitude 1.6 — bright enough to subtly alter the Scorpion's appearance and offer us one more version of the constellation.

■ **FRED SCHAAF** wishes he had been in the right part of the world to see Jupiter eclipse both components of Beta Scorpii in May 1971.

To find out what's visible in the sky from your location, go to skyandtelescope.org.

Plenty of Action at Dusk

Mercury, Venus, Mars, and the Moon meet in the evening sky.

SATURDAY, JULY 1

At dusk this evening, have a look toward the west to see a pair of planets that have wildly different brightnesses but are at similar points in their journeys and share a similar story. The planets in question are **Venus** and **Mars**. Both are losing ground to encroaching twilight as their respective apparitions wind down and they drift toward conjunctions with the Sun. In the case of the Evening Star, that occurs on August 13th, while the Red Planet holds off until November 18th. However, Mars will become essentially invisible to the naked eye much sooner than that — in the latter part of August. Tonight, the two planets are separated by just 3½°; however, they're worlds apart in brightness — Venus is a –4.7-magnitude beacon while Mars is a 1.7-magnitude ember.

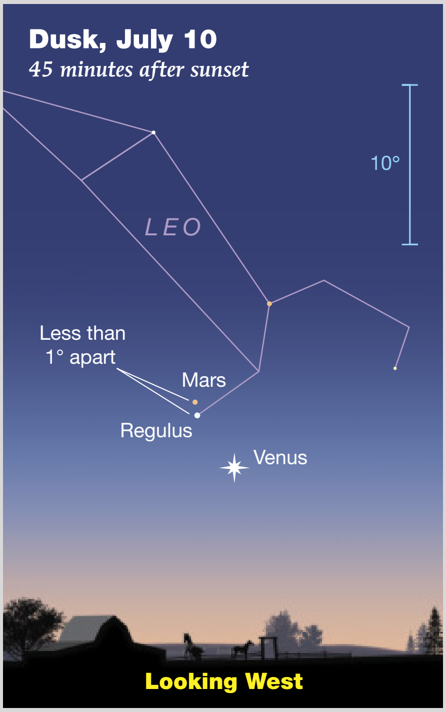
SUNDAY, JULY 9

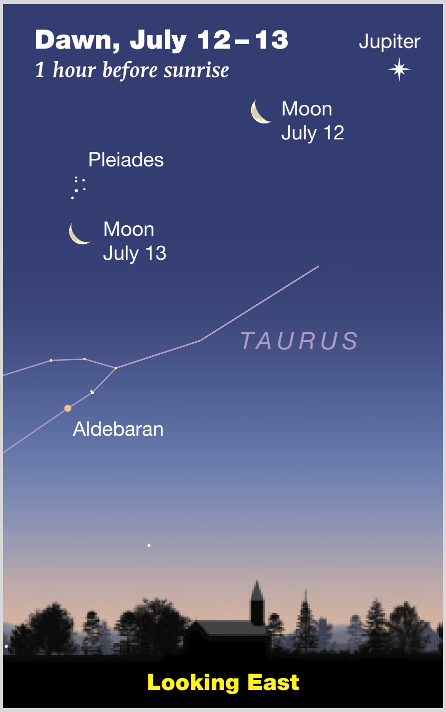
Tonight and tomorrow **Mars** will be parked very close to **Regulus**, the brightest star in Leo, the Lion. This is the first of two close planetary visits the star receives in July. This evening Mars is around ¾° from Regulus, though the gap between them is very slightly less on the evening of the 10th. The two objects are also closely matched in brightness, with the planet at magnitude 1.7 and the star shining at 1.4. That's not a huge span — can you perceive it? What makes the comparison slightly tricky is the contrasts in color — Mars is a peachy orange, while Regulus a cool bluish-white. Indeed, the view might remind you of the archetypal color-contrasting double star Albireo, in Cygnus (see page 54). The difference is that with Albireo, the orange component is six times brighter than the blue one.

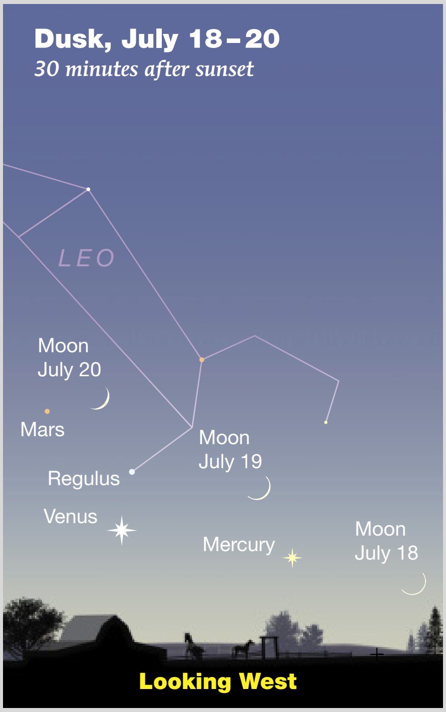
THURSDAY, JULY 13

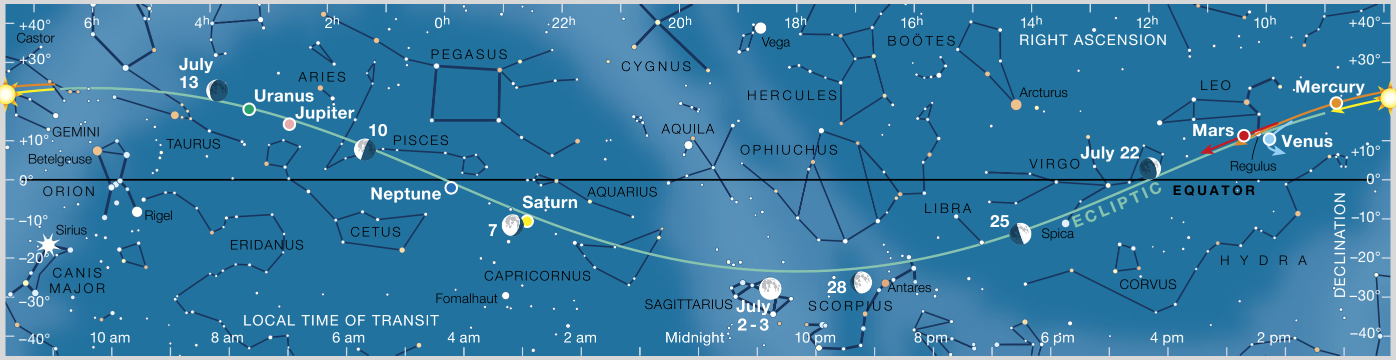
As busy as things are at dusk, the morning sky has its share of attractions, too. The month's finest dawn event is a nice pairing of the waning crescent **Moon** and the **Pleiades**, in Taurus. With less

▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon is shown three times its actual apparent size.





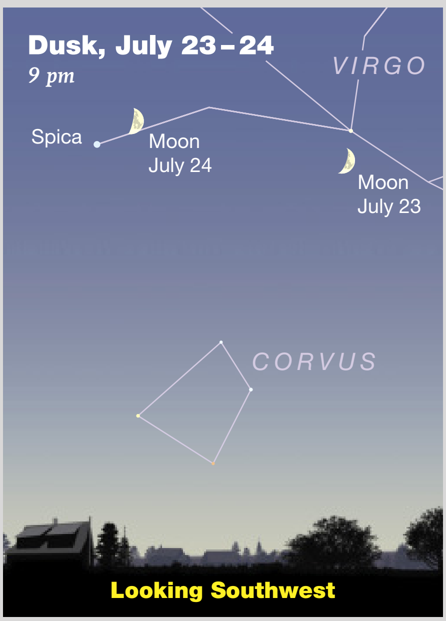




▲ The Sun and planets are positioned for mid-July; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st and an hour earlier at month's end.

than 2½° between the cluster and the crescent, this is both a fine naked-eye conjunction and a tempting binocular treat. The boost in magnification and light-gathering that binos provide will make the individual cluster stars easier to see and enhance the visibility of earthshine on the Moon's "unlit" face.

The very best meetings between the Moon and the Pleiades are those that occur late in the morning in summer or early in the evening in spring. It's during those two windows that the Moon is a slender crescent when it encounters the cluster. At other times of the year light from the increasingly illuminated Moon can overwhelm the cluster's stars, making for a much less satisfying sight.



WEDNESDAY, JULY 19

Activity low in the west-northwestern sky at dusk has been eye-catching all month but reaches a kind of climax tonight when a young, crescent **Moon** adds its luster to a jewel box of wonders. First, we have the aforementioned lunar crescent (still beautifully adorned with earthshine). Next, below and left of the Moon, is the can't-miss-it bright planet, **Venus**. Right of Venus and the Moon there's **Mercury**, shining at magnitude –0.4 as it approaches the midpoint of its current evening apparition. About 4° above Venus is **Regulus**, in Leo, while **Mars** lurks less than 6° above left of Regulus. Taken together, the five objects are an impressive collection of celestial gems.

Although I've highlighted the evening of the 19th here, the show remains captivating for several additional nights. On the 20th, the Moon has shifted eastward and makes an attractive quartet with Mars, Regulus, and Venus. And though the Moon has moved on by the 22nd, keep watching the gap between the solar system's two innermost planets shrink as Mercury ascends and Venus descends. By the end of the month the reigning Evening Star will surrender its crown and slip into the Sun's glare. It'll surface again next month, however, as the Morning Star.

MONDAY, JULY 24

This evening the **Moon** has its closest stellar encounter of the month when it approaches Alpha (α) Virginis, better known as **Spica**. How close? That depends on where you are. From the East Coast 2° will separate the waxing crescent and the 1st-magnitude star as they sink toward the west-southwestern horizon a little before midnight. However, observers on the West Coast get a slightly better show with the Moon sitting just 1½° from Spica. Because the star is neatly positioned just south of the ecliptic, it gets monthly visits from the Moon. The two meet up again on August 20th, and that's about it for evening pairings this year as Spica is overtaken by twilight. Their rendezvous resumes again at dawn in November.

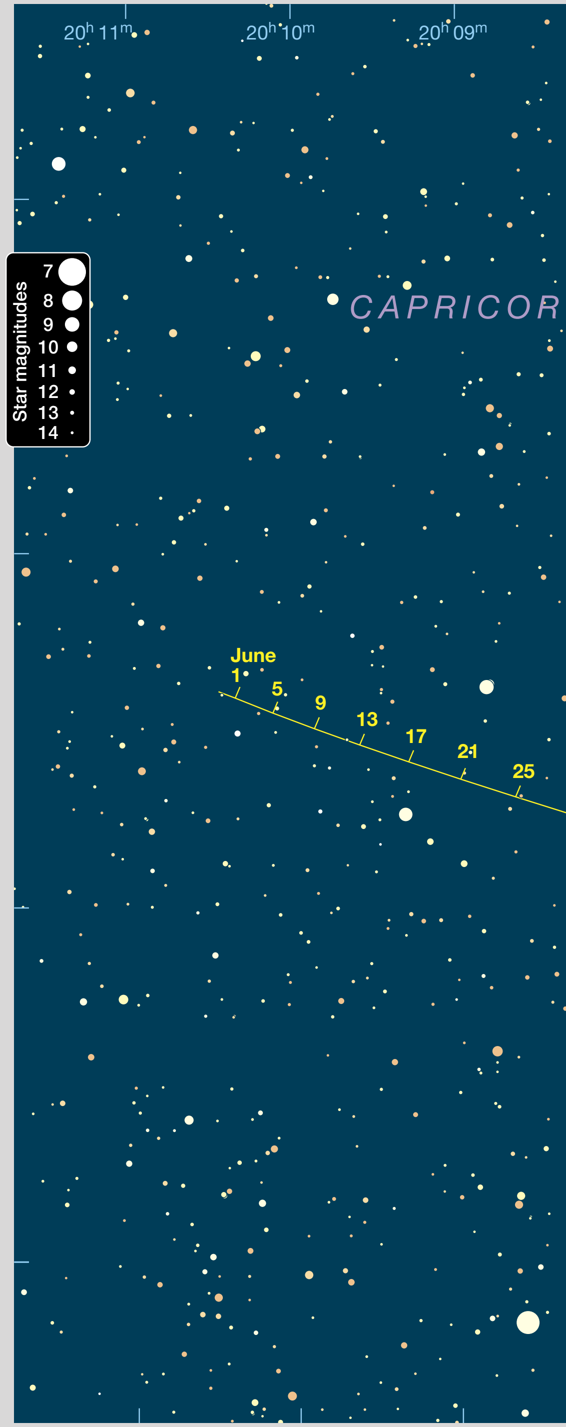
FRIDAY, JULY 28

July wraps up with a tight dusk pairing that includes **Regulus** and **Mercury**. If you kept watching the dusk action from the 19th onwards, this conjunction won't come as a surprise — Mercury has been edging closer and closer to the star each night and tonight they're a scant 10′ (¹⁄₆°) apart. That's close! However, there's an important caveat to note. Mercury shines brightly at magnitude –0.1 and Regulus at 1st magnitude, but they're very low in the west-southwest — just 6° above the horizon 30 minutes after sunset. You'll need an unobstructed view and (probably) binoculars, too, to claim both parts of this treat.

■ Consulting Editor **GARY SERONIK** never tires of watching the planets mix and match at dusk.

Distant Pluto Beckons at Opposition

July is the best time to challenge yourself by trying to catch this famous but faint dwarf planet.



Nothing screams minor planet like having a number in front of your name. We rarely think about it, but Pluto's complete astronomical designation is 134340 Pluto. Although some still prefer to consider it a *planet*, since 2006 the distant world has been categorized as a *dwarf planet*. The International Astronomical Union (IAU) defines a dwarf planet as a "an object in orbit around the Sun that is large enough to pull itself into a nearly round shape but has not been able to clear its orbit of debris."

When Clyde Tombaugh discovered Pluto in 1930, it stood alone. Calling it a planet made sense then, but now it has plenty of company in the outer solar system's Kuiper Belt, where maybe up to 200 dwarf planets reside. In similar fashion, astronomers initially considered the first asteroids discovered to be planets until their ranks grew and their true natures became apparent, placing them into a category of their own.

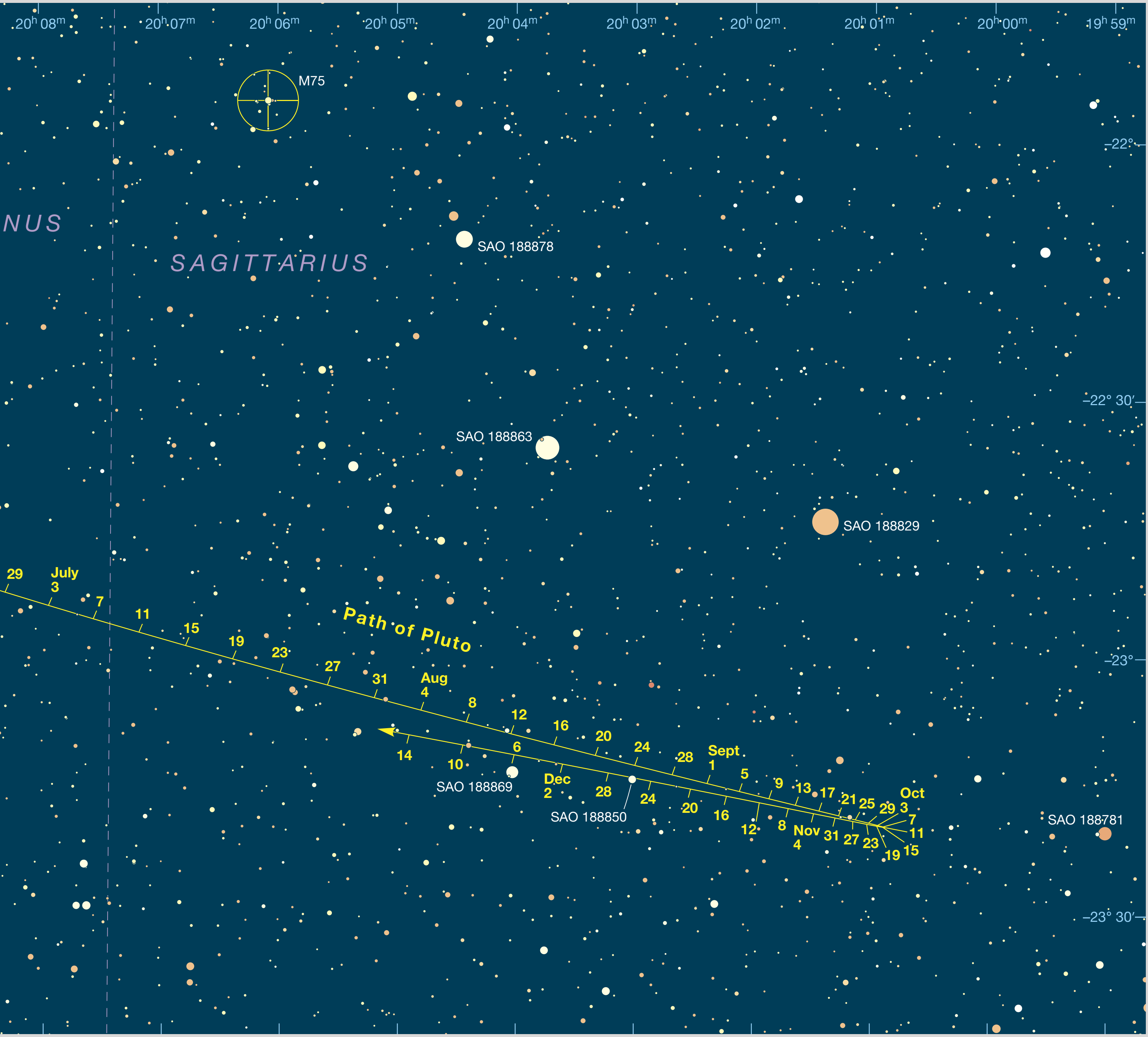
Whatever your personal views are on Pluto's standing, there's one thing all observers can agree on: It represents an enjoyable visual challenge. At opposition on July 22nd (4^h UT), Pluto glimmers at magnitude 14.4 — near the theoretical limit for an 8-inch telescope used under a dark sky. If you haven't already made Pluto's acquaintance, now is the time because the icy orb is sailing away and growing fainter with each passing opposition. It was most recently at *perihelion* (closest to the Sun in its orbit) in 1989 when it shone at magnitude 13.7, and it reaches *aphelion* (greatest distance from the Sun) in 2114, when it only musters magnitude 16.1.

Pluto begins the month in western Capricornus before crossing into eastern Sagittarius on the night of July 7–8. Its southerly declination of −23° poses an additional challenge for observers at mid-northern latitudes. From 40° north, the dwarf planet stands just 27° high when it crosses the meridian on opposition night. Begin your hunt after 11 p.m. local daylight time when Pluto reaches sufficient altitude for seeing conditions to be favorable.

Pluto is currently in the middle of nowhere with the nearest "bright" star being 6th-magnitude SAO 188829, about 1° to the west-northwest on opposition night. An easier-to-identify signpost to Pluto's field is the 8.6-magnitude globular cluster M75. Your quarry lies about 1° south of the cluster in mid-July.

Use our chart at right to pin down Pluto's position. Once you've identified a suspect, make a quick sketch showing its location in relation to several nearby field stars, and then return the next clear night to see if your suspect has moved. If it has, congratulations — you've sighted Pluto. Around opposition it drifts westward 1.4′ per night, a sufficient distance to detect at high magnification after just 24 hours. On the nights of July 23rd and 24th, the dwarf planet passes about 1.5′ north of a pair of 11th-magnitude stars separated by 26″. They make a convenient place to lie in wait and track Pluto's nightly perambulations.

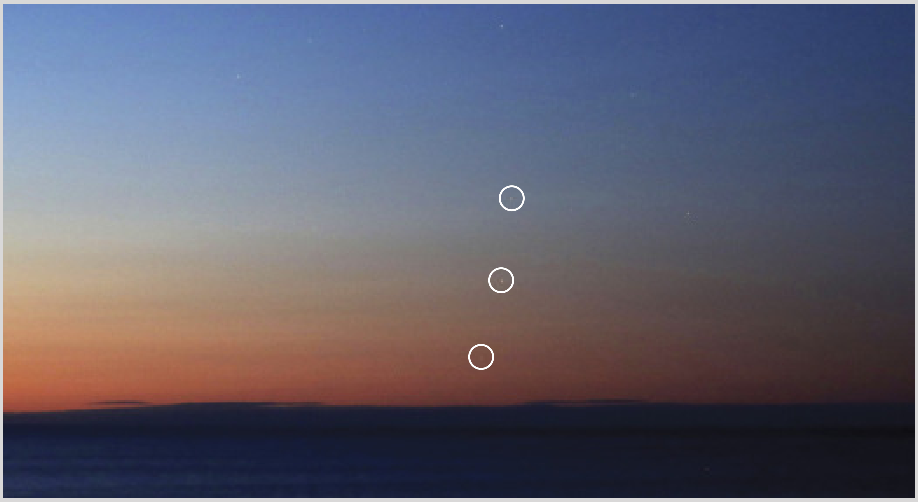
Once you have successfully corralled this remote world, consider all the wonders squeezed into that dim pinprick of



light. You're seeing something 70% the diameter of the Moon but more than 5 billion kilometers (3 billion miles) away. In your mind's eye, picture Pluto's cryovolcanoes, massive nitrogen-ice flows, towering mountains of granite-hard water ice, and methane-ice "sand" shaped into dune fields by the little world's surprisingly windy atmosphere. Perhaps most remarkably, Pluto may harbor a subsurface ocean of water kept liquid by the decay of radiogenic elements deep beneath the planet's crust. Wouldn't it be extraordinary if life somehow found a foothold there?

To cap off our brief visit to this alien world, there's an easy way to picture what it might be like to stand on its surface at high noon. At Pluto the Sun shines at magnitude –19.0, more than 1,200 times fainter that it does at Earth (–26.7). That's about the same level of illumination we experience 8 to 10 minutes before sunrise and after sunset — light enough to easily find your way around, and maybe even sandboard down a methane dune.

A First Glimpse of Orion's Belt



▲ The earliest the author has seen Orion's Belt appear from his home in Duluth, Minnesota, is July 30th. On that date the three stars (circled in the photo above) rose in mid-twilight, 1¼ hours before sunrise. To observe a star's heliacal rising, choose a location with an unobstructed horizon and bring binoculars to assist.

BOB KING

A STAR'S FIRST return at dawn after solar conjunction is called its *heliacal rising*. Historically, the most anticipated heliacal rising was that of Sirius, the brightest star in the night sky. Ancient Egyptian skywatchers noticed that Sirius returned into view at dawn shortly before the annual flooding of the Nile River.

One of my favorite sights is the heliacal rising of Orion's Belt. I get a kick out of seeing it in the summer sky in part because it's so incongruous with the season. Orion's easy enough to see at the start of dawn in late August, but I wanted to test my limit. With Lake Superior offering a near-perfect eastern horizon near my home in Duluth, Minnesota, I found a comfortable rock ledge along the shore a couple of years ago, then waited for the trio of stars to rise at dawn. Success came on July 30th.

Bellatrix, marking Orion's left shoulder, was the first to appear, followed by Betelgeuse. Although astronomical twilight was well underway by then, I felt hopeful. Then like a procession of ancient gods, Mintaka, Alnilam, and Alnitak rose in turn above the distant shoreline. All three were in view by 4:29 a.m. — a full hour after the start of morning astronomical twilight and with the Sun still 11.3° below the horizon. The last of the trio, Alnitak, stood only about 1° above the lake and initially I required binoculars to see it because of atmospheric extinction.

While nothing as dramatic as the flooding of the Nile occurred, seeing the first intimations of winter as the mosquitos tried their best to pester me made for a moment of quiet joy. Depending on your latitude and the duration of twilight, you may see the stars of Orion's Belt rise earlier in the month (if you're farther south) or possibly as late as the first week of August (if you're farther north).

You can plan your own outing by simulating local conditions with planetarium software such as *Stellarium*. And if you're a traditionalist, you might try for Sirius instead of Orion's Belt.

Action at Jupiter

THIS MONTH JUPITER becomes a viable telescopic target for the first time in its current apparition. By mid-July, it rises a little after 1 a.m. local daylight time and climbs to an altitude of nearly 45° half an hour before sunrise. That's easily high enough for the planet to escape the worst of our atmosphere's detail-destroying effects. On the 15th of the month, the Jovian disk shines at magnitude –2.3 and spans 38.0″. If you continue viewing Jupiter with your scope as twilight brightens, you'll notice a lovely color-contrast effect between the planet's creamy-yellow disk and gray-brown bands with the deep blue of the background sky.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

June 1: 1:15, 11:11, 21:07; **2**: 7:03, 16:59; **3**: 2:54, 12:50, 22:46; **4**: 8:42, 18:37; **5**: 4:33, 14:29; **6**: 0:25, 10:21, 20:16; **7**: 6:12, 16:08; **8**: 2:04, 12:00, 21:55; **9**: 7:51, 17:47; **10**: 3:43, 13:38, 23:34; **11**: 9:30, 19:26; **12**: 5:22, 15:17; **13**: 1:13, 11:09, 21:05; **14**: 7:00, 16:56; **15**: 2:52, 12:48, 22:44; **16**: 8:39, 18:35; **17**: 4:31, 14:27; **18**: 0:22, 10:18, 20:14; **19**: 6:10, 16:06; **20**: 2:01, 11:57, 21:53; **21**: 7:49, 17:44; **22**: 3:40, 13:36, 23:32; **23**: 9:27, 19:23; **24**: 5:19, 15:15; **25**: 1:10, 11:06, 21:02; **26**: 6:58, 16:54; **27**: 2:49, 12:45, 22:41; **28**: 8:37, 18:32; **29**: 4:28, 14:24; **30**: 0:20, 10:15, 20:11

July 1: 6:08, 16:04; **2**: 2:00, 11:56, 21:51; **3**: 7:47, 17:43; **4**: 3:39, 13:34, 23:30; **5**: 9:26, 19:22; **6**: 5:17, 15:13; **7**: 1:09, 11:05, 21:00; **8**: 6:56, 16:52; **9**: 2:47,

12:43, 22:39; **10**: 8:35, 18:30; **11**: 4:26, 14:22; **12**: 0:18, 10:13, 20:09; **13**: 6:05, 16:01; **14**: 1:56, 11:52, 21:48; **15**: 7:43, 17:39; **16**: 3:35, 13:31, 23:26; **17**: 9:22, 19:18; **18**: 5:14, 15:09; **19**: 1:05, 11:01, 20:56; **20**: 6:52, 16:48; **21**: 2:44, 12:39, 22:35; **22**: 8:31, 18:26; **23**: 4:22, 14:18; **24**: 0:14, 10:09, 20:05; **25**: 6:01, 15:56; **26**: 1:52, 11:48, 21:44; **27**: 7:39, 17:35; **28**: 3:31, 13:26, 23:22; **29**: 9:18, 19:14; **30**: 5:09, 15:05; **31**: 1:01, 10:56, 20:52

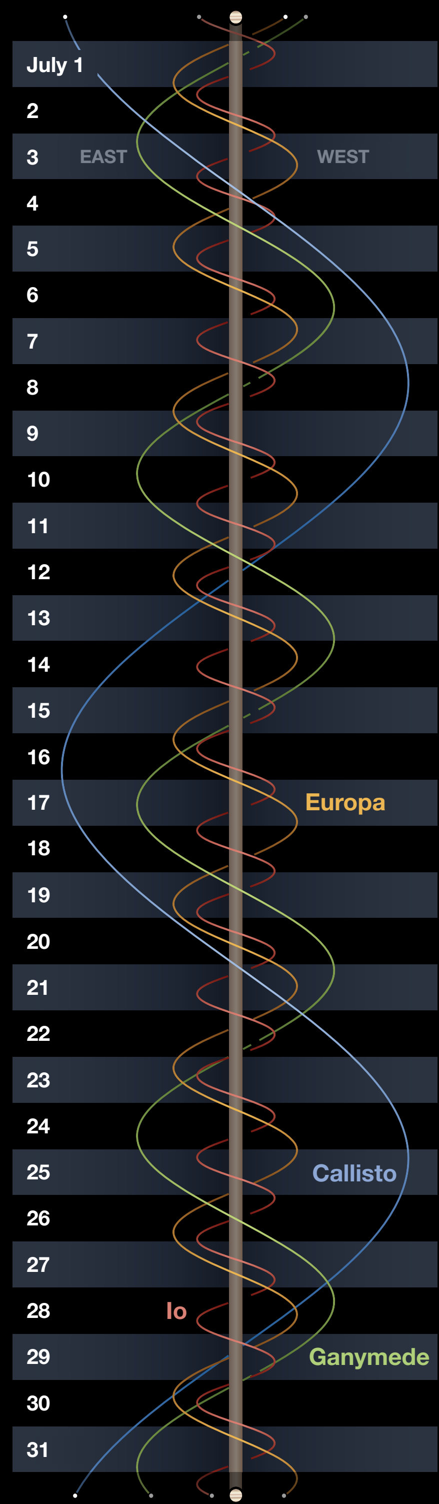
These times assume that the spot will be centered at System II longitude 41° on July 1st.

Phenomena of Jupiter's Moons, July 2023

July 1	1:29	II.Oc.R
	3:32	III.Ec.D
	5:34	III.Ec.R
	8:32	III.Oc.D
	10:19	III.Oc.R
	15:00	I.Ec.D
	18:24	I.Oc.R
July 2	12:13	I.Sh.I
	13:24	I.Tr.I
	14:22	I.Sh.E
	15:33	I.Tr.E
	15:41	II.Sh.I
	18:01	II.Sh.E
	18:10	II.Tr.I
	20:29	II.Tr.E
July 3	9:29	I.Ec.D
	12:54	I.Oc.R
July 4	6:41	I.Sh.I
	7:54	I.Tr.I
	8:50	I.Sh.E
	10:02	I.Tr.E
	10:04	II.Ec.D
	12:24	II.Ec.R
	12:31	II.Oc.D
	14:50	II.Oc.R
	17:44	III.Sh.I
	19:42	III.Sh.E
	22:53	III.Tr.I
July 5	0:35	III.Tr.E
	3:57	I.Ec.D
	7:23	I.Oc.R
July 6	1:10	I.Sh.I
	2:23	I.Tr.I
	3:19	I.Sh.E
	4:32	I.Tr.E
	4:59	II.Sh.I
	7:19	II.Sh.E
	7:32	II.Tr.I
	9:50	II.Tr.E
	22:26	I.Ec.D
July 7	1:53	I.Oc.R
	19:38	I.Sh.I
	20:53	I.Tr.I
	21:47	I.Sh.E
	23:01	I.Tr.E
	23:21	II.Ec.D
July 8	1:42	II.Ec.R
	1:52	II.Oc.D
	4:11	II.Oc.R
	7:34	III.Ec.D
	9:34	III.Ec.R
	12:51	III.Oc.D
	14:34	III.Oc.R
	16:55	I.Ec.D
	20:22	I.Oc.R
July 9	14:06	I.Sh.I
	15:22	I.Tr.I
	16:15	I.Sh.E
	17:30	I.Tr.E
	18:18	II.Sh.I
	20:38	II.Sh.E
	20:55	II.Tr.I
	23:13	II.Tr.E
July 10	11:23	I.Ec.D
	14:51	I.Oc.R
July 11	8:35	I.Sh.I
	9:51	I.Tr.I
	10:44	I.Sh.E
	12:00	I.Tr.E
	12:38	II.Ec.D
	14:59	II.Ec.R
	15:13	II.Oc.D
	17:32	II.Oc.R
	21:44	III.Sh.I
	23:42	III.Sh.E
July 12	3:09	III.Tr.I
	4:46	III.Tr.E
	5:52	I.Ec.D
	9:21	I.Oc.R
July 13	3:03	I.Sh.I
	4:20	I.Tr.I
	5:12	I.Sh.E
	6:29	I.Tr.E
	7:36	II.Sh.I
	9:56	II.Sh.E
	10:16	II.Tr.I
	12:34	II.Tr.E
July 14	0:20	I.Ec.D
	3:50	I.Oc.R
	21:32	I.Sh.I
	22:50	I.Tr.I
	23:41	I.Sh.E
July 15	0:58	I.Tr.E
	1:56	II.Ec.D
	4:16	II.Ec.R
	4:33	II.Oc.D
	6:52	II.Oc.R
	11:35	III.Ec.D
	13:34	III.Ec.R
	17:07	III.Oc.D
	18:44	III.Oc.R
	18:49	I.Ec.D
	22:19	I.Oc.R
July 16	16:00	I.Sh.I
	17:19	I.Tr.I
	18:09	I.Sh.E
	19:27	I.Tr.E
	20:55	II.Sh.I
	23:15	II.Sh.E
	23:38	II.Tr.I
July 17	1:55	II.Tr.E
	13:17	I.Ec.D
	16:48	I.Oc.R
July 18	10:29	I.Sh.I
	11:48	I.Tr.I
	12:38	I.Sh.E
	13:56	I.Tr.E
	15:13	II.Ec.D
	17:34	II.Ec.R
	17:54	II.Oc.D
	20:12	II.Oc.R
July 19	1:45	III.Sh.I
	3:41	III.Sh.E
	7:22	III.Tr.I
	7:46	I.Ec.D
	8:55	III.Tr.E
	11:17	I.Oc.R
July 20	4:57	I.Sh.I
	6:17	I.Tr.I
	7:06	I.Sh.E
	8:25	I.Tr.E
	10:14	II.Sh.I
	12:33	II.Sh.E
	12:59	II.Tr.I
	15:15	II.Tr.E
July 21	2:15	I.Ec.D
	5:46	I.Oc.R
	23:26	I.Sh.I
July 22	0:46	I.Tr.I
	1:34	I.Sh.E
	2:54	I.Tr.E
	4:30	II.Ec.D
	6:51	II.Ec.R
	7:13	II.Oc.D
	9:31	II.Oc.R
	15:37	III.Ec.D
	17:35	III.Ec.R
	20:43	I.Ec.D
	21:20	III.Oc.D
	22:52	III.Oc.R
July 23	0:15	I.Oc.R
	17:54	I.Sh.I
	19:15	I.Tr.I
	20:03	I.Sh.E
	21:23	I.Tr.E
	23:33	II.Sh.I
July 24	1:52	II.Sh.E
	2:19	II.Tr.I
	4:36	II.Tr.E
	15:12	I.Ec.D
	18:44	I.Oc.R
July 25	12:22	I.Sh.I
	13:44	I.Tr.I
	14:31	I.Sh.E
	15:51	I.Tr.E
	17:48	II.Ec.D
	20:08	II.Ec.R
	20:33	II.Oc.D
	22:50	II.Oc.R
July 26	5:45	III.Sh.I
	7:40	III.Sh.E
	9:40	I.Ec.D
	11:33	III.Tr.I
	13:00	III.Tr.E
	13:13	I.Oc.R
July 27	6:51	I.Sh.I
	8:12	I.Tr.I
	9:00	I.Sh.E
	10:20	I.Tr.E
	12:51	II.Sh.I
	15:10	II.Sh.E
	15:39	II.Tr.I
	17:55	II.Tr.E
July 28	4:09	I.Ec.D
	7:42	I.Oc.R
July 29	1:19	I.Sh.I
	2:41	I.Tr.I
	3:28	I.Sh.E
	4:49	I.Tr.E
	7:05	II.Ec.D
	9:26	II.Ec.R
	9:52	II.Oc.D
	12:09	II.Oc.R
	19:37	III.Ec.D
	21:34	III.Ec.R
	22:37	I.Ec.D
July 30	1:28	III.Oc.D
	2:11	I.Oc.R
	2:56	III.Oc.R
	19:48	I.Sh.I
	21:10	I.Tr.I
	21:57	I.Sh.E
	23:18	I.Tr.E
July 31	2:10	II.Sh.I
	4:29	II.Sh.E
	4:59	II.Tr.I
	7:14	II.Tr.E
	17:06	I.Ec.D
	20:39	I.Oc.R

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.

by Thomas A. Dobbins and William Sheehan

Suspense at Saturn

Will observers be treated to an atmospheric display this apparition?

We're overdue for a recurrence of one of the ringed planet's most arresting spectacles. Known as "Great White Spots" by analogy to Jupiter's iconic Great Red Spot, Saturn's colossal storms appear suddenly at intervals of about three decades and can expand to encircle the entire planet.

Shorn of its magnificent rings, Saturn would appear as a paler version of Jupiter. While Saturn's dusky belts and bright zones resemble Jupiter's richly detailed cloudscape, they are comparatively muted in contrast and less sharply defined. The blandness of features on Saturn is largely attributed to the planet's lower temperatures, arising from its greater distance from the Sun. As a result, Saturnian clouds form deeper in its atmosphere.

Saturn's weaker gravity greatly reinforces this thermal effect. Although the planet is just 15% smaller in diameter than Jupiter, it's only 30% as massive. The Jovian atmosphere is pulled much more powerfully toward the planet's center, so the pressure gradient is almost three times steeper than in Saturn's atmosphere.

Nevertheless, the ringed planet's distended atmosphere is similar in both structure and composition to Jupiter's, with a deck of water clouds at the bottom, a layer of ammonium hydrosulfide clouds in the middle, and clouds of frozen ammonia tinted by traces of sulfur and phosphorous compounds at the top. Above the ammonia clouds, Saturn's upper troposphere and stratosphere contain a murky haze of photochemical smog that washes out details and subdues colors.

These overlying aerosols obscure very dynamic meteorological activity. Saturn may appear quiescent compared to Jupiter, but its wind speeds are up to four times higher and its jet streams are much broader as well. Vertical convection in Saturn's atmosphere is also far more pronounced than within Jupiter thanks to the lower gravity and greater buoyancy. These factors play a key role in generating the massive atmospheric upwellings of its Great White Spots.

Throughout observational history, we've witnessed just six of these spots, occurring in 1876, 1903, 1933, 1960, 1990, and 2010. The 1903, 1960, and 2010 Great White Spots appeared at northern latitudes of 36°, 58°, and 38°, respectively. The far more spectacular events of 1876, 1933, and 1990 formed in Saturn's Equatorial Zone. This pattern suggests a cycle of roughly 30 years for outbreaks occurring alternately in the Equatorial Zone and at higher temperate latitudes, though the seemingly premature 2010 event broke the pattern. Curiously, each of the Equatorial Zone outbreaks first appeared at a hotspot located at a longitude extending from 290° to 315°. This calls to mind the vents that serve as the sources of Jupiter's South Equatorial Belt revivals (*S&T:* Sept. 2010, p. 50).

▲The intense 1990 equatorial storm imaged by the Hubble Space Telescope on November 9th of that year

All of these Great White Spots occurred during summer in Saturn's northern hemisphere, strongly suggesting a seasonal correlation. Although heating by the distant Sun is rather

▼This series of images recorded by NASA's Cassini orbiter shows the evolution of the 2010 Great White Spot over an 8-month period.

1990 EQUATORIAL STORM: NASA / JPL / STSCI; SERIES OF SIX SATURNS: NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE

feeble compared to the planet's internal store of heat, the effect of its 27° axial tilt is greatly augmented by the shadow cast by the rings, which blocks sunlight from reaching the tropical and temperate latitudes for long periods of time (*S&T:* Sept. 2021, p. 52). Saturn ponderously circles the Sun once every 29.4 years, so each season lasts more than seven Earth years.

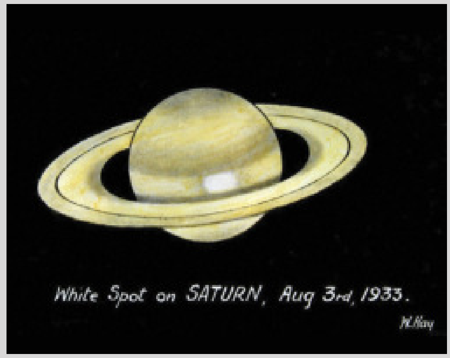
The first indication of a Great White Spot is the appearance of a tiny, brilliant "pearl." This is typically followed by multiple, closely spaced eruptive nuclei, which are violent convective upwellings reminiscent of the cumulonimbus towers of terrestrial thunderstorms. When instruments aboard NASA's Cassini spacecraft monitored the 2010 storm from Saturnian orbit, they detected intense radio static emitted by lightning generated in its fierce turbulence.

The warm plume cools as it expands, causing billowing clouds of white ammonia crystals to freeze out high above the main cloud canopy. The visible wake of the intense storm expands very rapidly in an eastward direction from its trailing end and within only a week can extend to a length of more than 100,000 kilometers (62,100 miles) to become one of the most striking planetary phenomena visible through amateur telescopes. The equatorial Great White Spots were visible even through apertures as small as 3 inches.

As they continue to expand, the clouds slowly lose contrast with their surroundings. Zonal winds shear them into increasingly dissipated streaks that eventually blend into the surrounding zones. Although expansion in latitude is much less pronounced, these storms can displace or even obliterate adjoining belts. Activity usually subsides after several months, although outbreaks in the Equatorial Zone persisted for 4 years following the Great White Spot of 1990.

In 2015, Caltech planetary scientist Andrew Ingersoll proposed a detailed mechanism for the seasonal genesis of the Great White Spots. He suggested that when Saturn's upper atmosphere undergoes seasonal cooling, it initially becomes less dense as water vapor condenses and rains out. After achieving a density minimum, there is a reversal as the remaining desiccated air (composed almost entirely of hydrogen and helium, the lightest of all gases) continues to cool. Convection is suppressed when the density of the upper atmosphere is low but resumes when its density increases sufficiently. It's this interaction of descending cold, dry air with rising warm, moist air that triggers titanic storms. The decades-long lag before the onset of storms arises from the very slow rate at which Saturn's massive atmosphere radiates heat into space.

Comparable planet-encircling storms don't occur on Jupiter because Jupiter's axial tilt is only 3°, so seasonal effects are practically nonexistent. In addition, Jupiter's upper atmosphere is drier than Saturn's, which is replenished by the water supplied by a steady rain of ice particles from the ring system. A lesser though still significant source of water comes from geysers on the icy moon Enceladus. No other satellite in the solar system is known to influence the chemical composition of its parent planet.



▲ British comedian and amateur astronomer Will Hay discovered a Great White Spot outbreak using his 6-inch Cooke refractor on August 3, 1933.

Summer solstice in Saturn's northern hemisphere occurred in May 2017, and the autumnal equinox is coming up in May 2025. It's high summer right now in Saturn's northern hemisphere, and it's been over three decades since a Great White Spot appeared in the planet's Equatorial Zone. Observers should monitor this region closely during the current Saturn observing season. If you need any encouragement, bear in mind that of the six Great White Spots we have witnessed, four were first detected by vigilant amateur astronomers.

■ Despite anticipating storms on Saturn, Contributing Editors **TOM DOBBINS** and **BILL SHEEHAN** don't consider themselves meteorologists.

SKETCH: WILL HAY, COURTESY OF THE ROYAL ASTRONOMICAL SOCIETY / MARTIN MOBBERLEY

COATHANGER CLOSE-UP The delightful Coathanger, first detected with the naked eye, wasn't logged by legendary observers Charles Messier or William Herschel. A chance alignment of 10 stars whose distances range from 237 to 1,132 light-years, the alluring asterism is worth close inspection in a telescope. The tiny open cluster NGC 6802, visible in this image, lies immediately east of the Coathanger.

RON BRECHER

A Cosmic Coathanger Caper

A superb binocular target, the beloved Coathanger also invites telescopic inspection.

Poor Vulpecula, the Fox. An inconspicuous constellation buried in the summer Milky Way, the sly celestial fox tries hard not to be seen — and largely succeeds. Vulpecula contains no stars brighter than 4th magnitude. Yet Vulpecula is home to an attractive group of stars first clearly identified over a thousand years ago.

The mottled patch of starlight became known as al-Sufi's cluster, in honor of Abd al-Rahman al-Sufi, a Persian astronomer who first noted it in AD 964. Almost 700 years later, the Italian astronomer Giovanni Hodierna independently cataloged the object. Seattle, Washington amateur Dalmero Brocchi prepared a detailed chart of the intriguing field in the 1920s for the American Association of Variable Star Observers — hence the label Brocchi's Cluster on star atlases. The cluster graduated to professional status as **Collinder 399** (Cr 399) thanks to a comprehensive survey of open clusters that Swedish astronomer Per Collinder compiled in 1931. Today, stargazers know it simply as the Coathanger.

Call it what you will, the Coathanger isn't a true open cluster in which the stars are gravitationally bound to one another. Instead, it's an *asterism* — a chance alignment of suns lying at vastly different distances. Even so, Cr 399 is curiously compact and evocatively shaped. Its 1½°-wide pattern is distinctive in binoculars and sparkling in small telescopes. Recently, I explored the Coathanger and its immediate surroundings with my 4.7-inch (120-mm) f/7.5 apochromatic refractor. But any backyard scope will do, so join me for a quick Cosmic Coathanger Caper.

Getting There

The famous double star **Albireo**, or Beta (β) Cygni, is our gateway to the Coathanger zone. Albireo features a 3.2-magnitude orange sun and a 4.7-magnitude blue neighbor 34.9″ away. The colorful components are eye-candy gorgeous in a wide-angle, 30-mm eyepiece generating 30× on my 120-mm refractor. The low magnification tightens the tandem and includes a generous amount of surrounding sky. The scope's panoramic view greatly intensifies the beauty of the contrasting jewels set against the glittering Milky Way.

Like the Coathanger, Albireo's attractiveness is an accident of alignment. Measurements by the Gaia astrometry mission indicate that the bright orange sun is 60 light-years closer to Earth than the fainter blue sun. So, unless contrary evidence comes to light, Albireo will remain categorized as an optical double rather than a physical binary.

The Coathanger resides in southern Vulpecula, near the border with Sagitta, the Arrow. How does Albireo get us there? I have a simple "Anser" to that. An 8°-long line extended south-southwestward from Albireo through 4.5-magnitude **Anser**, officially Alpha (α) Vulpeculae, leads directly to Cr 399. *Anser* means "the Goose," a remnant celestial figure from the late 17th century when Polish astronomer Johannes Hevelius declared this area of sky as "Vulpes cum Ansere" — the Little Fox with the Goose.

Let's linger on orangey Anser before moving on to our main target. The star is an easy catch in any finderscope; indeed, it's occasionally naked-eye visible in my gray suburban sky. Nothing else along the Albireo-to-Coathanger path is as bright as Anser. Moreover, Anser is accompanied by a deep-yellow, 5.8-magnitude star 7′ to the northeast. From that handy combo it's a 4½° hop to the Coathanger.

I love the Coathanger nickname; the modern-day moniker is delightfully appropriate. Ten stars of 5th to 7th magnitude convincingly delineate the familiar shape of a household hanger.

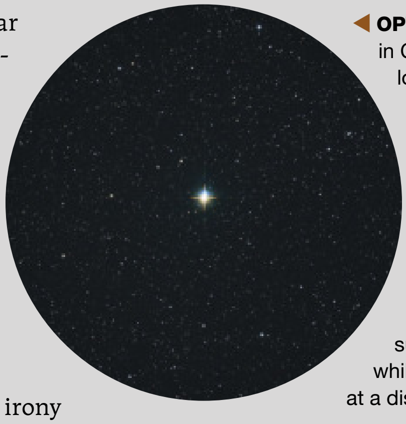
Hanging Around

The effect in my 10×50 binoculars is striking — a horizontal bar formed by six stars in a remarkably straight, 1½°-long row, running almost precisely east-west, plus four additional stars outlining the angular hook. It really is a perfect coathanger. That said, Northern Hemisphere binocular observers will notice that the silly thing is upside-down.

Ah, but the Coathanger appears right-side up in my straight-through 8×50 finderscope — and remains upright (albeit backwards) when I use a 90° diagonal on the refractor. The scope frames the entire asterism beautifully in a single field of view, provided I employ (as with Albireo) very low magnification. At 30×, five of the stars in the row-of-six shine blue-white, while the westernmost sparkle is yellow-orange. The four-star hook offers two bluish dots and two of a distinctly warmer hue.

Dominating the Coathanger's hook is 5.2-magnitude **4 Vulpeculae**, the asterism's leading light. Yellowish 4 Vul is a triple system listed in the Washington Double Star Catalog as HJ 2871. The dependable WDS lists a 10.0-magnitude companion 13.5″ east of 4 Vul, but I'm not certain I've glimpsed it in my 120-mm apo, even at 200×. The other member of the trio lies 50.9″ southwest of 4 Vul. Alas, this wider star also eluded me, flickering feebly at magnitude 11.7 — right at the limit of my modest scope laboring under a soupy city sky. (I can, however, pick up both companions of 4 Vul if I use my 10-inch f/6 Newtonian reflector at 218×.)

Only ¼° northeast of 4 Vul, is 5.8-magnitude HD 182955 (it has no Flamsteed number). This *K*5 orange giant anchors a loose quintuple array known as **Struve (Σ) 2521**. Four of the attendants shine at about magnitude 10.5 — faint but doable, while the fifth star is well out of reach of my suburban apo. One attendant (star B) is 29.0″ north-northeast of the primary, another (C) is 75.1″ north-northwest, and the third (D) is 152.1″ east-northeast. The apo captures the spread-out threesome at 100×, though 200× pulls in the group much more clearly. I chuckle at the irony of using 200× while observing the sprawling Coathanger!



OPTICAL ILLUSION? Albireo in Cygnus is arguably the loveliest double star in the northern heavens. However, it's likely not a true binary system. Although the two stars appear close together in our scopes, according to results from the Earth-orbiting Gaia astrometry mission, the bright orange sun is 330 light-years away, while the dimmer blue star is at a distance of 390 light-years.

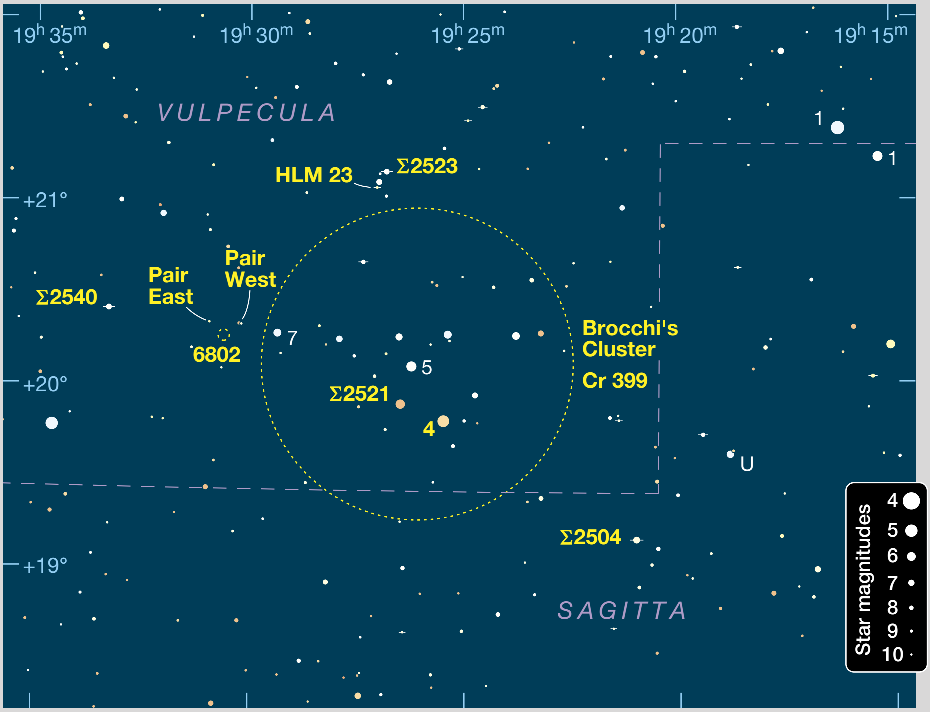
GARY SERONIK

Outside the Hanger

Let's explore the area around the Coathanger. A line from Σ2521 through 4 Vul, extended 1¼° southwestward, crosses the border into Sagitta where it passes an L-shaped trio of stars. The most prominent point in the little L is a double star called **Σ2504**. Comprising 7.0- and 9.0-magnitude components 8.7″ apart, Σ2504 unveils its binary nature at 38×.

One degree north of the Coathanger is a picturesque region dominated by two stars. The 7.2- and 8.0-magnitude markers lie 4.1′ apart on a northwest-southeast slant. The northwestern star is **Σ2523**, a headlight binary whose 8.0- and 8.1-magnitude elements, 6.4″ apart, are a slender split at 38×. The southeastern star is single, but directly south of it is a double called **HLM 23**. HLM must stand for Horribly Low Magnitude, because the stars weigh in at 10.5 and 11.0. Fortunately, they're separated by 17.0″ and resolve well at 56×.

The east end of the Coathanger's horizontal bar is established by 6.3-magnitude 7 Vulpeculae. Just



AN UPSIDE-DOWN COATHANGER A lovely little arrangement of 5th- to 7th-magnitude stars known as the Coathanger is located almost 8° southwest of Albireo. For mid-northern observers, the Coathanger hangs high in the south (albeit upside-down) all summer long.

▶ **HANGING AROUND** Buried in the Vulpecula Milky Way, the Coathanger asterism, also known as Collinder 399, is an eye-catching splotch of glitter in a country sky. Even amid city lights, Cr 399 looks great in binoculars.

⅓° further east are two dim doubles, aligned east-west, within 10′ of each other. They're not listed in the comprehensive Washington Double Star Catalog, so I'm dubbing them **Pair West** and **Pair East**. The former comprises 9.1- and 10.0-magnitude stars separated by 47″, while the latter has 9.8- and 11.3-magnitude stars 33″ apart. Both pairs show well at 100×.

There's more. Slightly below the two pairs is **NGC 6802**, an 8.8-magnitude open cluster. Only 5′ across, NGC 6802 claims approximately 200 members, none brighter than 14th magnitude. This is one tough target for suburban scopes, but with averted vision I can detect it at 100×. On the best nights, it's a grainy bit of coathanger fluff sharing the high-power field with my West and East doubles.

We'll complete our tour with the challenging double star, **Σ2540**, a touch more than ½° beyond Pair East. Formed by 7.5- and 9.2-magnitude pinpoints a scant 5.4″ apart, Σ2540 wins my seldom appreciated, frequently ignored Itty-Bitty Binary award (Coathanger category). The delicate duo resolves beautifully at 100× in the refractor.

Hooked Yet?

The binocular-friendly Coathanger is definitely worth inspecting with a telescope. If, like me, you observe from a badly light-polluted city, you can nail everything I've described above, with the possible exception of open cluster NGC 6802. If your sky is better than mine, even that tiny bit of coathanger fluff might hang nicely in your eyepiece, too.

■ Contributing Editor **KEN HEWITT-WHITE** has never actually traced out the constellation Vulpecula in the night sky.

Coathanger Collection

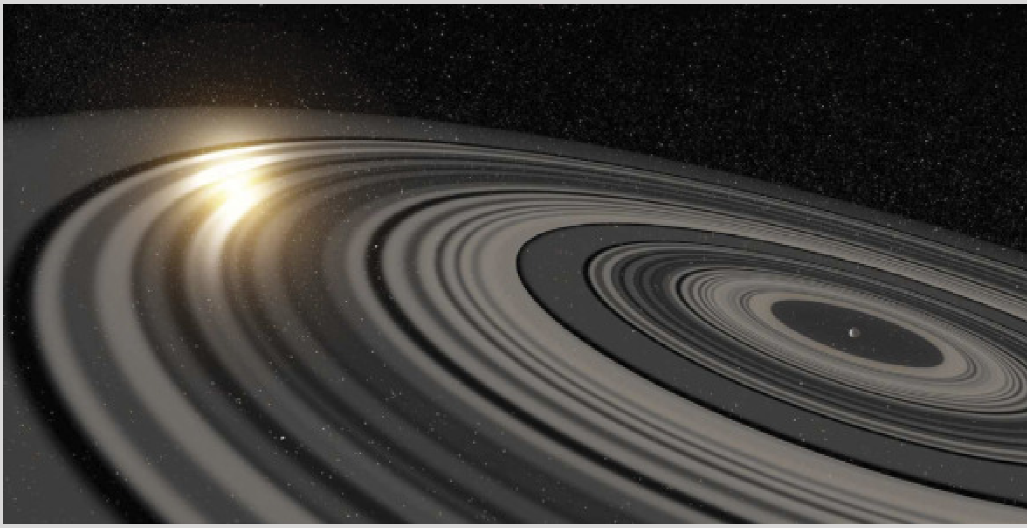
Object	Type	Mag(v)	Size/Sep	RA	Dec.
Cr 399	Asterism	3.6	~60′	$19^h\ 25.4^m$	+20° 11′
Albireo	Double star	3.2, 4.7	34.9″	$19^h\ 30.7^m$	+27° 58′
4 Vul AB	Double star	5.2, 10.0	13.5″	$19^h\ 25.5^m$	+19° 48′
4 Vul AC	Double star	5.2, 11.7	50.9″	$19^h\ 25.5^m$	+19° 48′
Σ2521AB	Double star	5.8, 10.5	29.0″	$19^h\ 26.5^m$	+19° 54′
Σ2521AC	Double star	5.8, 10.5	75.1″	$19^h\ 26.5^m$	+19° 54′
Σ2521AD	Double star	5.8, 10.6	152.1″	$19^h\ 26.5^m$	+19° 54′
Σ2504	Double star	7.0, 9.0	8.7″	$19^h\ 21.0^m$	+19° 09′
Σ2523	Double star	8.0, 8.1	6.4″	$19^h\ 26.8^m$	+21° 10′
HLM 23	Double star	10.5, 11.0	17.0″	$19^h\ 26.8^m$	+21° 10′
Pair West	Double star	9.1, 10.0	47.0″	$19^h\ 30.2^m$	+20° 20′
Pair East	Double star	9.8, 11.3	33.3″	$19^h\ 30.9^m$	+20° 20′
NGC 6802	Open cluster	8.8	5′	$19^h\ 30.6^m$	+20° 16′
Σ2540	Double star	7.5, 9.2	5.4″	$19^h\ 33.3^m$	+20° 25′

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

ALAN DYER

Explore Exorings

The hunt for rings around other planets is on.



▲ **SUPER SATURN** Saturn's rings are very close in to the planet, within its *Roche radius*. But the *Hill sphere* is where the gravitational influence of a planet is stronger than that of its star (and is much bigger than the Roche radius). Material in the Hill sphere of a young planetary system is a vast structure, such as that of J1407b (above), which is some 200 times more extensive than Saturn's rings. If Saturn had such rings, it would appear as large as about 10 full Moons! (See *S&T:* Sept. 2020, p. 34.)

RON MILLER / NASA

We know that rings encircle the giant planets in our solar system — Jupiter, Saturn, Uranus, and Neptune all orbit the Sun accompanied by an entourage of rings. We also know of more than 5,000 confirmed exoplanets today, many of which are giants. It follows that they'd have rings, too.

But exoplanets are many light-years away and hard to find in their own right. If they're so tough to spot, how can we go about finding their rings? Matthew Kenworthy (Leiden University) is taking a unique approach to this task. And he has called upon the amateur community to help him out.

Big, big rings. While examining archival data of the young star J1407 (short for 1SWASP J140747.93-394542.6), Erik Mamajek (University of Rochester) and his graduate student at the time, Mark Pecaut, noticed that it exhibited a series of complex eclipses over a period of about two months. Kenworthy's subsequent analysis showed that not only was the star's dimming likely due to an unseen substellar companion — dubbed J1407b — passing in front of the star from our perspective, but the model that most satisfactorily fit the data pointed to a *ringed* exoplanet. Further analysis revealed that the ring system is *huge*, with some 30 rings spanning around 120 million kilometers in diameter. That's about the size of Venus's orbit around the Sun.

We can't see *exorings* directly, but instead light from the star acts like a backlighting flashlight. If we can detect this starlight, then we can measure the distribution of material around the companion, which could tell us how much gas and dust there is and whether there are clear clumps or gaps that might be caused by moons.

Finding suitable candidates for further study, though, proved challenging. But one day a friend of Kenworthy's tagged him on, of all things, an ASAS-SN Twitter post. The All-Sky Automated Survey for Supernovae automatically surveys the entire sky every night down to about magnitude 18. As its name implies, it's mainly primed to search for new supernovae and other transient events. But the event Kenworthy's friend had pointed him to was no supernova: A star, named J0600 for short, had started exhibiting complex eclipses.

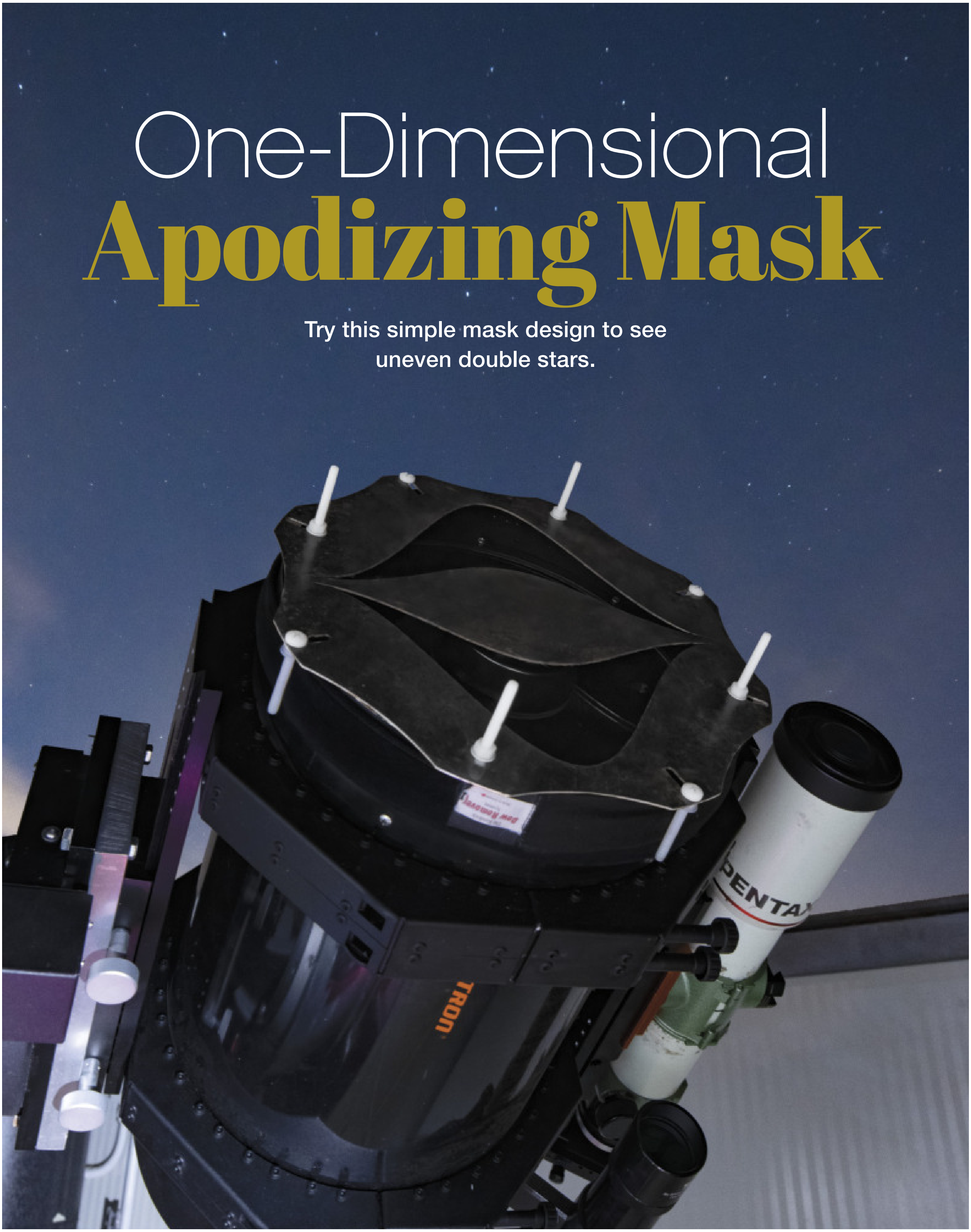
Amateurs help out. The stars that Kenworthy is after are very similar to our Sun. They're on the main sequence and are "quiet and boring for a few years until they undergo these weird dimming episodes," he says. Professional telescopes' finite time is largely dedicated to observing the faintest objects in the sky — it's tough to get them to consistently observe these targets. And so for his objects of interest, which are well within reach of amateur scopes at around magnitude 12 or so, Kenworthy turned to the American Association of Variable Star Observers, with its cohorts of willing and capable astronomers armed with hefty backyard scopes.

The support of the AAVSO is crucial: The data are not only immediately available, but the different wavelengths tell us the nature of the material passing between us and the star. If more blue light is blocked than red, we know there's dust. Once this information is in hand, coupled with detections of weird eclipses, Kenworthy turns to the big professional telescopes for targeted data. He's currently writing a paper on J0600 — and among the coauthors are several AAVSO observers.

Kenworthy notes that spitting out weird light curves is not ASAS-SN's primary goal (remember, it's supernovae they're after). "But to me it's gold dust," he says. "Because they're willing to share their data, it's opening up a brand-new subfield. We couldn't have done this 10 years ago." The combination of the internet (including social media), able amateurs, and the surge in citizen science is enabling this fun and curious new science.

If you're interested in looking for exorings, keep an eye on **https://is.gd/aavso_campaigns**. And, if you happen to spot unusual flickering, make sure you let Kenworthy and his team know.

■ Observing Editor DIANA HANNIKAINEN is fascinated by planets' Hill spheres.



One-Dimensional Apodizing Mask

Try this simple mask design to see uneven double stars.

EMMANUELE SORDINI

Observers use aperture masks to improve the view through a telescope, particularly under unsteady seeing. Such masks tend to fall into one of three categories. The first is off-axis, or stop-down, masks. These reduce the aperture to minimize the blurring effects of atmospheric seeing and avoid the influence of a central obstruction. These masks can produce occasional crisp, albeit lower-resolution views. The second type is focusing masks for astrophotography, such as those popularized by Pavel Bahtinov, Andrei Oleshko, and others (*S&T:* Jan. 2020, p. 30). The third kind is *apodizing masks*, which are designed to improve the view by modifying the diffraction properties of the telescope to help resolve close double stars in the eyepiece and on camera.

The most common design of the latter type is a two-dimensional, circularly symmetric apodizing mask intended to modify the image at all angles. The goal is to decrease the amount of light in the diffraction rings of a star's image, though it comes at the expense of some resolution. These apodizers typically don't work very well because the window-screen material typically used to construct the apodizer blocks a significant amount of light, and there's no easy way to vary the transmission.

But approaching the aperture in only one dimension opens up the possibility of smoothly varying transmissions in one axis. Using this approach, the apodizer doesn't need to be constructed from window screen.

◀ **MASKING FOR STARS** Seeing the fainter companion star in an unequal double can be challenging. This apodizing device makes a gap in the veil of diffraction surrounding the brighter star.

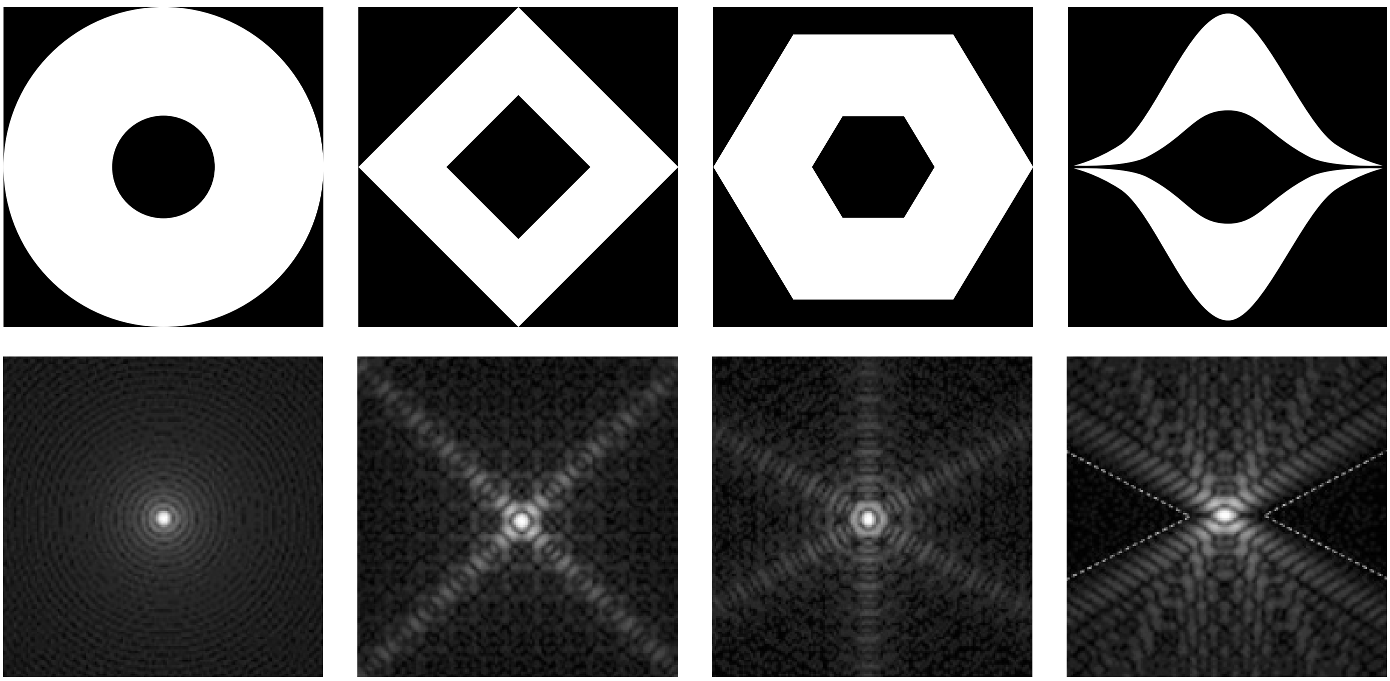
Thinking in One Direction

One-dimensional apodizers are beneficial for observing or imaging targets along a single axis, particularly double stars with components having large differences in brightness. These unequal doubles are difficult to see, and photographing them is even harder due to the limited dynamic range in digital detectors. The dazzle of the brighter star swamps the dimmer companion. The intended effect of apodization is to clear away much of the diffraction effects, allowing the observer to photograph and see dimmer stars than would otherwise be visible in the glare of diffraction.

So, how is a one-dimensional apodizer shaped? According to the geometric theory of diffraction, we only witness the effects of diffraction at right angles to the edges of an aperture. If we can ensure that there are no edges tangent to a fan-shaped range of angles, then that range shouldn't display diffraction effects, other than the overall effective aperture within that angle range.

This diffraction-pattern shaping is possible if you're willing to sacrifice some resolution along one axis in the field of view. The shape of this apodizing mask can vary from a square aperture oriented as a diamond, to a hexagon that offers greater resolution and a brighter image. However, these simple geometric forms don't actually optimize the apodization.

A better option is to make a mask that mimics a Gaussian-type profile (a bell-shaped curve), as seen in the rightmost mask below. Gaussian apertures produce very dark images far from the central spot. This design incorporates a smaller, sec-



HAROLD SUITER

▲ **APERTURE EFFECTS** This series of images shows a progression of aperture shapes with computer-generated simulations of the diffraction patterns each produces below. The left image simulates a telescope with a 33% central obstruction. The fan-shaped regions of darkness created by the Gaussian-mask at far right are outlined for emphasis.

ondary mask as a flattened version of the outer mask shape (resembling a stylized eye) to avoid permitting the secondary mirror's diffraction to spoil the effect of the main aperture. Results using two these masks (seen on the facing page) show Sirius imaged through the hexagonal mask and the Gaussian mask, compared to an image through an unmasked aperture. Both the hex mask and the Gaussian apertures produce good results. Notice that the unmasked aperture at the far left failed to reveal Sirius B.

The Gaussian apodizer isn't designed to split very close doubles, but rather it clears away part of the diffraction pattern in order to image very dim companion stars. One interfering factor is stray light due to underlying atmospheric turbulence, residual roughness in the telescope's mirror or corrector plate, or even dust and smudges on the optical elements.

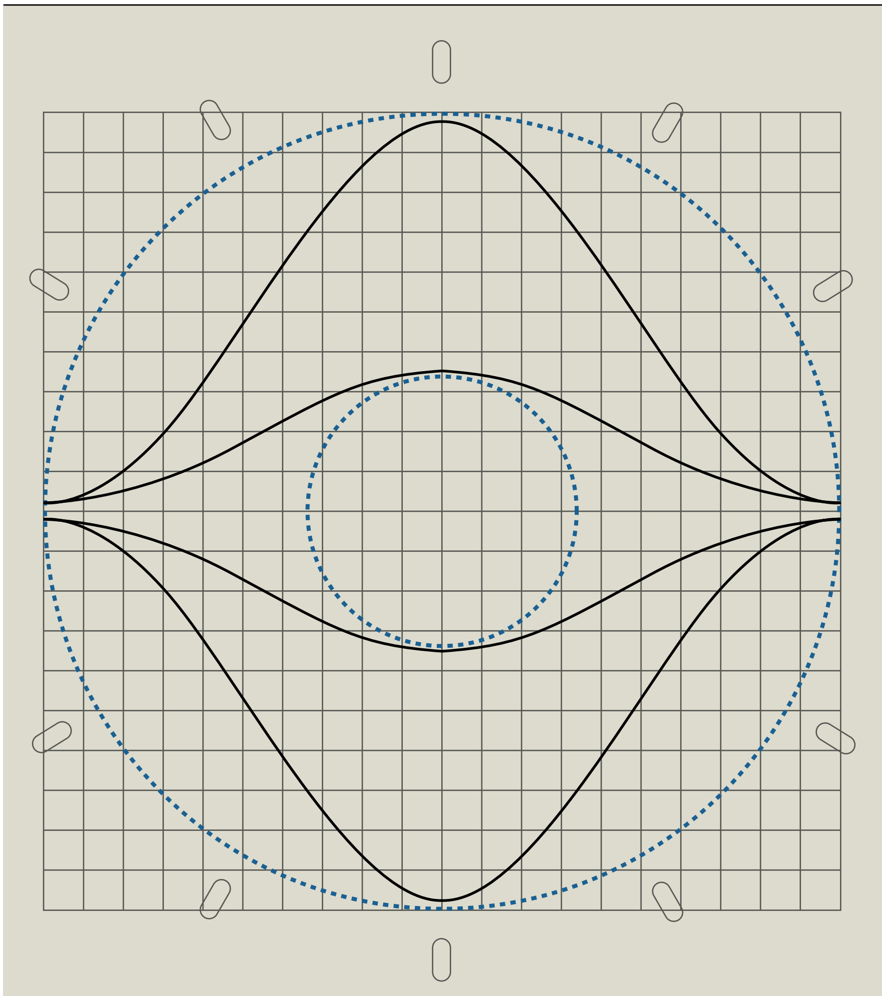
The mask is best suited for use with large refractors, or Maksutovs and Schmidt-Cassegrain catadioptrics, in which the secondary mirror is supported by a corrector plate or meniscus lens. Newtonians are less desirable for this work because the secondary-mirror support spider creates diffraction spikes in unfortunate directions, though this can be mitigated if you can rotate the OTA.

Construction of the Mask

Our mask is quite easy to make. A template is available for download at **https://is.gd/1dmask** and is designed to fit an 11-inch Schmidt-Cassegrain. The shape is based on a similar form seen in an article published in the 1960s, but it can be designed using any Gaussian-style curve. It can be printed on 11 × 17-inch paper, or even multiple sheets of 8½ × 11-inch paper. You then glue these printouts to the material the mask will be cut from. The design is scalable, though you should avoid making the top and bottom edges of the mask touch the edges of the telescope aperture because this will create its own source of diffraction.

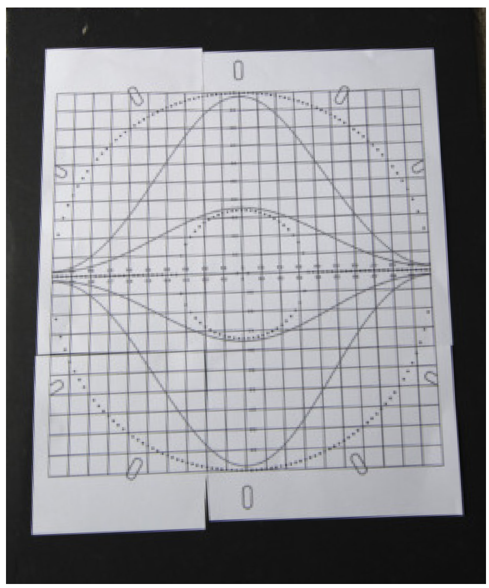
The mask doesn't need to be centered precisely to have the same Gaussian-type form. Note that the two aperture patterns are separated vertically to allow the secondary cover mask to connect to the outer mask. Without this, the smaller apodizer would swing loose and be difficult to keep aligned to the outer mask.

The shape of the secondary cover mask is simply a fraction of the outer Gaussian curve, but it doesn't need to be precisely the size shown. What is required is that its curve be similar but less aggressive than the outer mask's edge. So, if

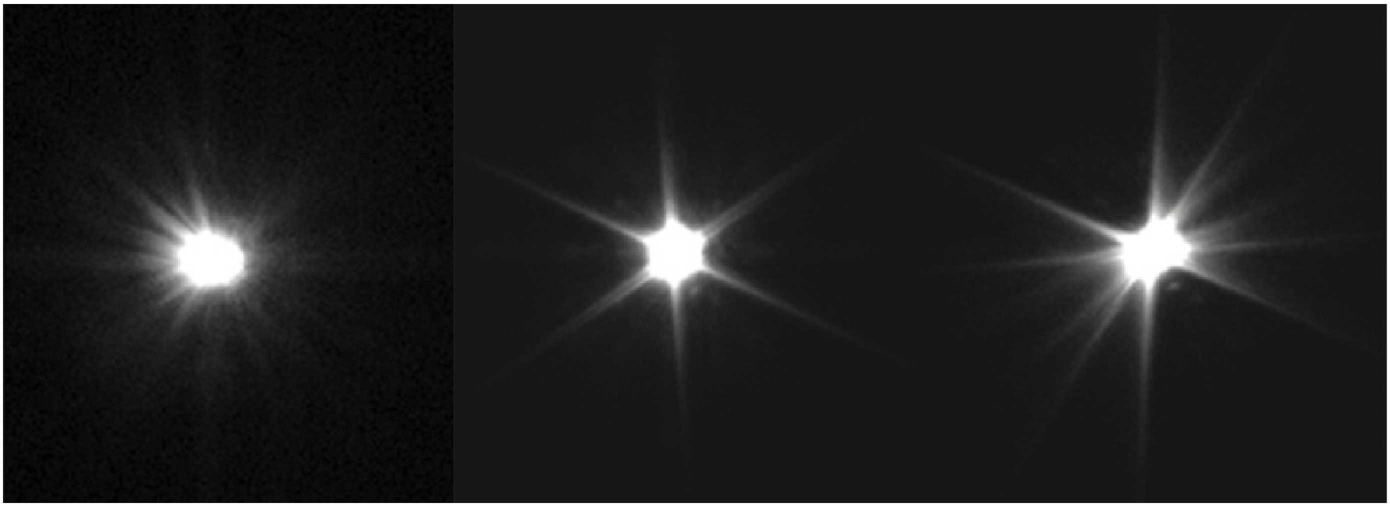


◀ **EYE MASK** Our single-axis, Gaussian apodizing mask pattern is designed for telescopes with 33% obstructions. It's available for download as a PDF file at **https://is.gd/1dmask**.

▼ **SCALABLE PRINTING** This template is easily scaled to fit larger apertures by printing and cutting the pieces then gluing them to foam core so that they don't shift as you cut through the material. The main thing to avoid is having the top and bottom of the curve overlap the outer edge of your telescope aperture. You can also modify the template to shrink the obstruction mask if your telescope's secondary is smaller than 33%.



TEMPLATE: EMMANUELE SORDINI; GLUED TEMPLATE: SEAN WALKER / S&T



▲ **DETAIL IN THE DARKNESS** These pictures show Sirius imaged by Emmanuele Sordini through his 11-inch Schmidt-Cassegrain without a mask (left), with a hexagonal mask (middle), and with a Gaussian mask (right). Sirius B only appeared with a mask in place.

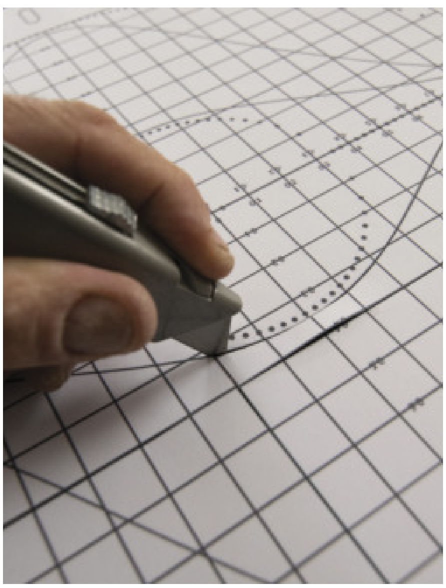
your telescope has a smaller secondary obstruction, you can shrink the secondary mask to let in more light, if desired.

Make the printout of the template using a high-quality inkjet or laser printer. Then glue it to a sheet of black foam core using a glue stick so that it adheres firmly but neither the paper nor foam core gets saturated with glue. Be sure to flatten out any wrinkles on the printout. Once this is done, cut out the mask with an X-Acto knife, box cutter, or other precision cutting tool. The curved profiles must be followed carefully — cutting these requires quite a bit of patience but is crucial because they need to be as smooth as possible. A bit of sanding will help clean up the edges.

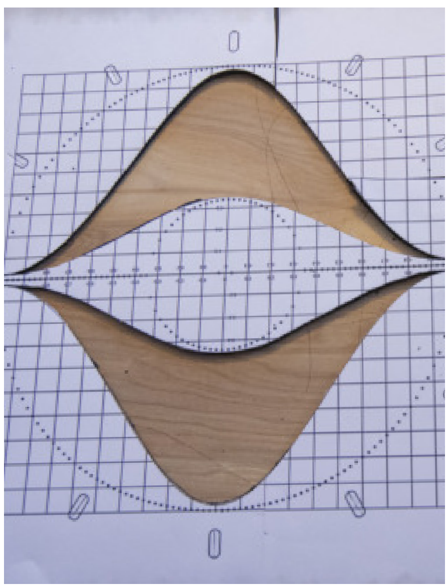
Once the cutting is complete, use the slot markings on the printout to install nylon bolts in place to center the mask on the front of your optical tube (we used 6-mm bolts). You can remove the paper printout from the mask, since the thin sheet of paper will be exposed to humidity and wrinkles quite easily.

Another option is to have the mask laser-cut from 2-mm-thick metal plate. The final product is far more durable and allows for precise positioning of the nylon bolt slots, not to mention there will be less diffraction from small errors along the edges.

The result is a metal mask weighing about 700 grams (1½ pounds) or less, which shouldn't create balancing problems. Some metals are prone to rusting, so you should paint the



▼ **FOLLOW THE PATTERN** Cut the mask using an X-Acto knife or other sharp tool that produces clean edges.



▼ **ADDING BALANCE** After cutting the pattern, carefully remove the pieces.

▼ **ALL DONE** After you've removed the pattern, all that's left to do is install the mounting screws along the edge.

CREATING THE MASK SERIES: SEAN WALKER / *S&T* (3)

mask matte black on both sides, which also has the benefit of minimizing reflections. Finally, the nylon bolts and nuts are screwed in the slots to fit the mask firmly on the front of your OTA.

Using the Mask

Some preliminary preparations are needed when using this mask. First, you must determine the orientation of the field of view so that the mask can be set at the correct position angle for each double star. You can find these angles in most double-star listings as well as several places online — an excellent resource is Stelle Doppie at **stelledoppie.it**. This website provides a comprehensive listing and a powerful search engine. With it you can look for ranges of separation, primary star magnitudes, and ranges of differences in magnitude. Look for targets close to the meridian so you can image them when they're highest.

Since the mask is symmetrical, it can accommodate any double star position angle on either side of the meridian by rotating it up to 180°.

You can temporarily indicate position angle reference ticks with labels, Post-it notes, or even with a grease pencil mark on the outside of the optical tube. Two reference indexes are needed if you intend to revisit the targets multiple times in an evening — one for each side of the meridian. But simply eyeballing the mask orientation is also effective and reliable.

◀ A sturdier and more aesthetically pleasing result is possible by cutting the mask from a metal plate, which has the added benefit of smooth, clean edges.

Once you've determined the mask orientation, the setup is ready for use. For imaging unequal double stars, long exposures aren't necessary, so an uncooled CMOS camera like those used for planetary imaging are well-suited to the task. We used a QHY5III290M monochrome camera, which has 2.9-micron pixels and produces an image scale of 0.21 arcseconds per pixel at the prime focus of a Celestron C11 SCT.

As with imaging the planets, atmospheric turbulence and heat sources close to the telescope play a large role in the quality of your results. Be sure you've allowed enough time for the optical tube to cool down before beginning an imaging session.

Next, focus the telescope without the mask in place so that the image is bright enough to permit focusing on fainter stars. If you measure the full-width, half-maximum value of stars to focus, choose one close to your target or use the pair's brightest component. Since you'll be imaging at high magnification, an electric focuser will make focusing easier.

▲ **MASK UP** *Left:* The Gaussian mask is in place and ready for use. *Right:* The nylon screws grip along the outside of the dew-heating band surrounding the telescope aperture.

EMMANUELE SORDINI (3)

Now, slew to your chosen target, center it in the field of view, and place the apodizer mask on your telescope. Increase the exposure length and, if necessary, the camera's gain until the distorted diffraction pattern of the brightest star becomes clearly visible. Rotate the mask so that the diffraction pattern's gap matches the position angle of the double. Note that increasing the gain also reduces the dynamic range in the recorded image, so it's preferable to use longer exposure over higher gain settings if possible.

Increase the exposure time and/or gain once more until the dimmer companion just becomes visible on your monitor. In most cases, the primary star will become saturated — just be sure the dimmer companion isn't engulfed in the primary's glare.

When that's accomplished, you can begin recording. Take at least 50 frames in an uncompressed format like FITS or record an SER video in the camera's high-bit mode — typically 10-, 12-, or even 16-bit-depth in order to capture the maximum brightness range. Live stacking can also produce good results (see the May issue, page 60). If the seeing is unstable, you may get better results if you use longer exposures and record more frames, or record longer videos in order to increase your chances of catching those fleeting, steadier moments. Double stars don't move on short time scales, so the only limits are the atmosphere and your computer's storage space.

Since you can't extract astrometric nor photometric data from saturated stars, try recording several sequences with as short exposures as you can to avoid saturating the brighter star. Later stacking and processing may allow you to tease the dimmer companion from the background even if it wasn't visible while recording. This way you can compare the magnitudes and spacing of the two components.

In Practice

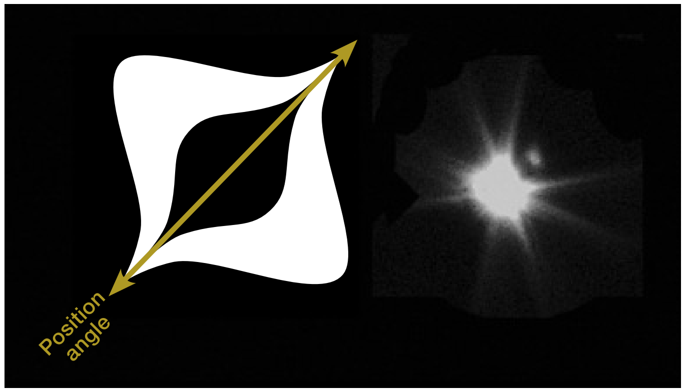
The mask improves the visibility of faint, close doubles most of the time. For example, the pictures of FF Aquilae at right show the effect of a couple seconds delay between imaging runs. In the left image, the dimmer star is in the dark region. In the right image, the companion star is much less noticeable, most likely due to poor seeing.

The final two figures at right showing 16 Aurigae and δ Geminorum are typical imaging runs. In both cases the mask clearly helped resolve the secondary stars.

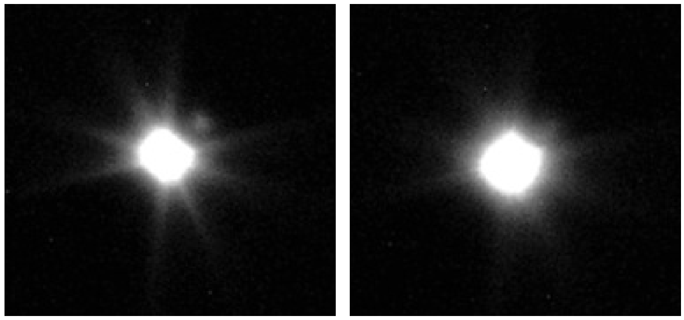
This simple apodizing mask is helpful for observing and imaging uneven doubles, so long as the observer takes into account its inherent limitations. While it doesn't dampen any seeing problems, it does part the curtain of diffraction to reveal companion stars hundreds of times fainter than the primary.

■ **EMMANUELE SORDINI** is an Italian astrophotographer who showcases his work at **www.bloomingstars.com**. **HAROLD SUITER** is author of *Star Testing Astronomical Telescopes* available at **shopatsky.com**.

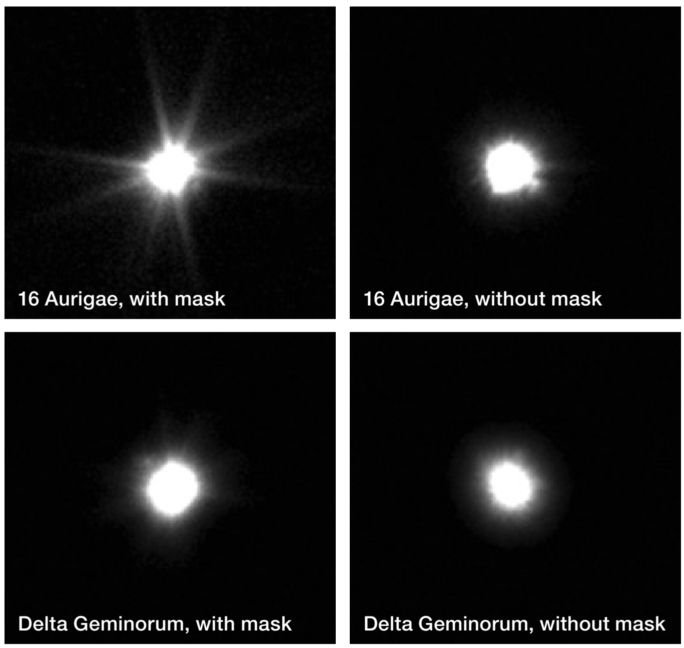
EMMANUELE SORDINI (7)



▲ **IN THE POCKET** Simply rotate the mask until one of the two gaps in the primary star's diffraction pattern aligns with the position angle of the secondary. The fainter star of the pair should then become visible.



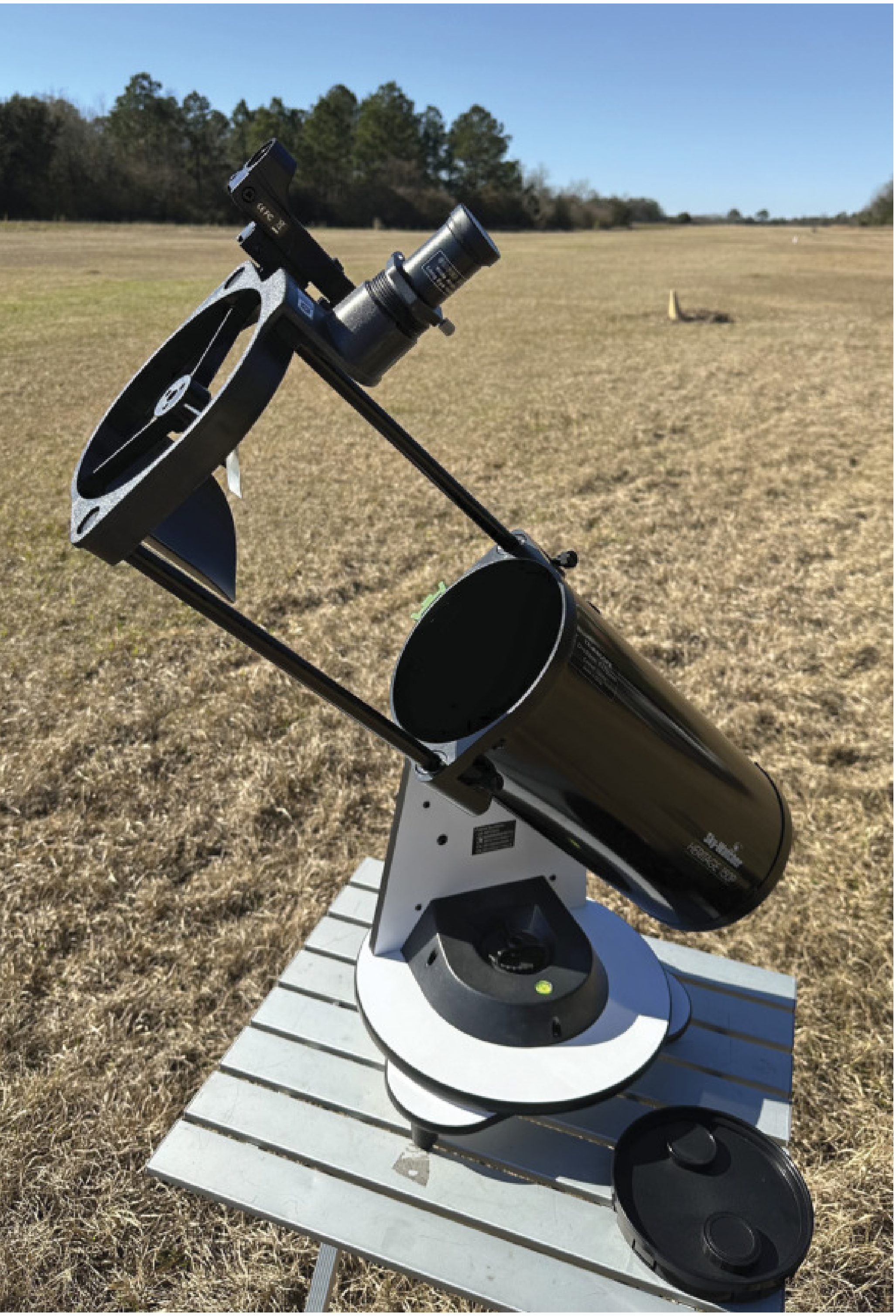
▲ **SOME SUCCESS** Double star FF Aquilae was sometimes recorded through the mask under varying conditions.



▲ **TO SEE OR NOR TO SEE** In most cases, the Gaussian mask made the difference between clearly seeing a double's fainter companion or not. The pictures above show the 4.8-magnitude star 16 Aurigae captured with the mask (left) and without (right), in which the 10.6-magnitude companion isn't quite separated. In another example below the first, the mask made all the difference between recording the magnitude-8.2 companion of Delta Geminorum (left) or not at all (right).

A Tabletop Go To Dobsonian

Sky-Watcher's Virtuoso GTi 150P adds a computerized mount to this capable 6-inch Newtonian.



Sky-Watcher Virtuoso GTi 150P

U.S. Price: $470

skywatcherusa.com

What We Like

Excellent optics

Accurate Go To

Freedom Find keeps alignment

What We Don't Like

Helical focuser rough motion

Manual doesn't cover control app

WHEN I REVIEW a telescope, I like to look at the manufacturer's ads to see what they think deserves mention. What's special about the instrument? Sky-Watcher's advertisement for the Virtuoso 150P Tabletop f/5 Dobsonian reflector leads off with "These ain't no toys." Which (despite the double negative) started me thinking.

The past 40 years of amateur astronomy has been the age of huge telescopes — a time when a 12-inch-aperture instrument is considered "small" by some. When I was a young astronomer, however, the 6-inch (150-mm) Newtonian reflector was the norm, and amateurs did amazing work with it. A scope of this size is both "portable and powerful," as Sky-Watcher's ad also states.

The Virtuoso Package

I hadn't used a 6-inch reflector in a long time and was hopeful this one might be worth coming home to, but I was skeptical. The manufacturer makes a lot

◀ The Virtuoso 150P is a 6-inch, f/5 Newtonian reflector on a compact Go To mount controlled with either the manufacturer's *SynScan* or *SynScan Pro* smartphone apps.

ALL IMAGES COURTESY OF THE AUTHOR

of claims about the capabilities of this fairly inexpensive scope. In addition to featuring a collapsible tube, 94% reflectivity "Radiant Aluminum Quartz" mirror coatings, and two wide-field "Super" eyepieces, the Virtuoso is also equipped with dual-axis drives and a Go To computer. The ad also says the telescope can find and track more than 10,000 objects when used with a free smartphone app. That's a big claim for a 150-mm scope.

The Virtuoso arrived double boxed. It took a little doing to extract the scope, which was tightly held in place by its foam packing. Thankfully, the scope was easy to assemble and nearly ready to go out of the box. All you need do is mount the tube on the single-arm, alt-azimuth mount with its Vixen-style dovetail bracket, attach the finder, and extend the front section of the truss-style tube.

The rear 38 centimeters (15 inches) is a solid (steel) tube, but the front 30.5 cm is composed of two small rods attached to a ring that holds the secondary-mirror assembly, focuser, and a light shield opposite from the focuser. In its stowed position, the front portion is collapsed, making the whole tube assembly only a little over 40 cm long. When extended, the rods are locked in place with two nylon bolts.

◀ The Virtuoso 150P upper tube assembly showing the helical focuser, light baffle opposite the focuser, and secondary mirror

Sitting on a table in my den, the telescope looks attractive. The shiny black steel tube, the futuristic-looking truss assembly, and the pretty black-and-white-finished mount dispelled some of my doubts — until I noticed the whole thing was tilted. One of the three plastic feet on the base was missing, broken off during shipping, no doubt, leaving a gaping hole in the particle-board base. Although the telescope was sitting on a piece of packing foam in the box, that apparently wasn't enough to prevent shipping damage. Fortunately, the foot was easy to reattach with the aid of some Elmer's Glue.

With the scope assembled, I had a look at the accessories. The included 25-mm and 10-mm eyepieces didn't inspire much confidence. Both have metal barrels, but their upper assemblies are plastic. Also included is a unit-power red-dot finder. After some digging through the manual (which covers three different models of Virtuoso scope), I learned that the finder mounts on the tube upper assembly. I switched it on but saw no red dot — batteries not included. Luckily, I had the required CR 2032 cell on hand.

The telescope's computer and motor are powered by 8 AA batteries. That's convenient for occasional use but can

▲ The tube of the Virtuoso 150P measures 69 centimeters (27 inches) with the focusing ring extended and collapses to 41 cm for transport and storage. Weighing a total of 8.6 kilograms (19 pounds), the scope should be easy for most observers to carry around and set up.

▲ Both the primary and secondary mirror cells are fully adjustable with three alignment screws each. The center of the primary mirror is marked to aid collimation.

▲ The telescope's unit-power red-dot finder attaches to the secondary ring above one of the two trusses. The helical focuser secures eyepieces with two knurled thumbscrews.

get expensive quickly if you use the telescope often. Rechargeable cells worked for me. The best bet, though, is the AC/DC power adapter Sky-Watcher sells for $49. One caveat is the power input port rotates with the telescope, so the adapter's cord can get wrapped up in the mount.

Before first light, I always check the alignment of the primary and secondary mirrors. Sky-Watcher includes a "collimation cap," a plastic cap with a small hole in its center that fits in the focuser and aids optical alignment. The company also conveniently marks the center of the primary mirror with a circular sticker. While I used my own collimation tool, I verified the cap also showed the mirrors in alignment. The instructions in the manual will allow most beginners to adjust the scope properly. Out of the box, mirror alignment was pretty close anyway.

The telescope's focuser is a helical model, a threaded tube that screws in and out to focus. I'm not a fan of the design, and this one seemed poorer than most. Its threads are coarse, and black paint on the unlubricated threads makes the action particularly rough. It's a bit wobbly and lacks a lock screw to reduce wobble and hold focus in place.

Before using the telescope, users have to download the *SynScan Pro* app to allow the Virtuoso to find and track objects. An optional SynScan hand control can be used with the telescope (and adds $155 to the price). The app, however, is free from both the Apple App Store and the Google Play Store and runs on most any smartphone or tablet. There's also a basic *SynScan* app, but it has fewer options and was slower to connect to my iPhone. However, the pro version downloaded and installed without problems.

I spent some time reading the *SynScan Pro* app documentation I downloaded from the Sky-Watcher website at **https://is.gd/synscan_app** (the printed manual included with the scope says little about the app). Ideally, these instructions should be included in the main manual. Despite the docu-

▲ The telescope comes with 25- and 10-mm long-eye-relief "super" eyepieces as well as a simple but functional collimation cap to help users align the optics.

ment's lack of illustrations and step-by step instructions, after reading it and exploring the help files built into the app, I was ready to go. However, I still had to decide where to use the scope. Sky-Watcher calls this a "tabletop" Dobsonian, and they aren't kidding. The eyepiece is a mere 76 cm off the

▲ The optical tube assembly attaches to the single-arm Dobsonian mount with a standard Vixen-style dovetail clamp. This permits users to balance the scope when adding heavier eyepieces and Barlows, or to swap in other OTAs, provided they clear the Virtuoso's drive base.

▲ The outside face of the altitude arm contains the battery compartment as well as inputs for an optional SynScan hand paddle, a DC power input, and a SNAP port to control certain DSLR and mirrorless cameras (seen left to right, respectively). The Wi-Fi power indicator flashes red twice per second when the scope is on.

▲ The Virtuoso 150P focuser stands just 76 centimeters above the ground at best, so users will need a table or some other lift to bring the scope to a comfortable viewing height.

ground when the scope is pointed at the zenith. So, I placed the Dob on a small folding aluminum camp table. It was reasonably steady but not the Rock of Gibraltar, and the spot where I placed it on my driveway wasn't quite level. Would these things lead to an "alignment failed" message?

Go To Alignment

I thought on the first night out I'd simply concentrate on getting the Go To working. With the Virtuoso 150P, this starts by connecting to a smart device. Some Wi-Fi enabled telescopes I've used have had trouble connecting and staying connected. Not this scope. I turned it on, chose "SynScan 5500" in my iPhone's Wi-Fi menu, and the app connected and stayed connected. I could walk to the other side of the backyard and still maintain connection.

So far, so good. Next came aligning the system. There are four options in the app: 1-Star Alignment, North-Level Alignment (two stars), Brightest Star Alignment (two stars), and 3-Star Alignment. In each case, the scope initially has to be in its "Home Position" with the scope pointed north (with the aid of Polaris) and the tube level (with the help of the built-in bubble level). Typically, the scope slews to alignment stars the user chooses from a list arranged in order of magnitude. However, with the Brightest Star option, you center the first star in the eyepiece by using the direction buttons on the app screen before the scope slews automatically to the second star to complete the alignment process.

I tested each alignment method and found the three that use multiple stars comparably accurate. Often Brightest Star was handy for my suburban backyard, because the alignment list only includes the brightest stars and planets. The 1-Star routine worked best when observing objects near the selected alignment star.

With the Virtuoso in Home Position, I tightened the altitude and azimuth clutches enough to hold the telescope in place but left them loose enough to move the telescope easily by hand. The app's Freedom Find feature allows you to push the Virtuoso by hand without ruining the Go To alignment, thanks to the presence of auxiliary encoders on each axis.

The Virtuoso mount includes a SNAP port to control some DSLR and Mirrorless cameras, though it wasn't needed to take this snapshot of the Moon with an iPhone held up to the 25-mm eyepiece.

After selecting North-Level Alignment, I chose two stars from the list in SynScan Pro and, after the scope slewed to them, centered each in the eyepiece. *SynScan Pro* provides nine slewing speeds to accommodate coarse and fine centering. My first selection was Polaris, but the second "star" was actually Saturn. The Virtuoso had no trouble using planets for alignment. After centering both, the app displayed "alignment successful." And it was! Every target I requested, from horizon to horizon, was visible in the field of the 25-mm eyepiece (30×) when a slew stopped. This, despite my table being not quite level.

Pleasant Observing

It was time to have some observing fun with early fall objects. While *SynScan Pro* only displays lists of potential targets — there are no star charts — it works well. My first stop was M15 in Pegasus, a bright but compact globular cluster. The slew ended with the object in the eyepiece field, I centered it with the direction buttons, and I inserted the 10-mm eyepiece. The helical focuser wasn't as bad as I feared; it was mostly screwed in at infinity focus and not too wobbly. I had a look and rubbed my eyes — was I seeing some resolution in this tight cluster? I ran inside, fetched a 4.7-mm eyepiece for higher magnification, and had a good, long look. I was seeing not just the brilliant core, but, yes, a splash of tiny stars.

Every object I visited showed more detail than I remembered a 6-inch being capable of producing. M27, the Dumbbell Nebula, was riding high and was a spectacle, especially when I added a light-pollution filter to the 25-mm eyepiece. The oculars turned out to be better than I expected. They both feature comfortable 65° apparent fields, good eye relief, and while edge-of-field performance isn't great — stars ¾ away from the center began to look like comets — I mostly concentrated on what was in the middle of the field and just enjoyed.

At low power, the scope has an expansive field of view and is well-suited for wandering around the Summer Milky Way. Staring at the globular cluster M71, I was taken by the beauty of the image. This 6-inch had enough light-gathering power to pull in hordes of background suns.

There was one problem, though. Despite the presence of a baffle opposite the focuser, stray light from neighbors'

lights sometimes spoiled my views. Most big Dobsonians have cloth or plastic light "shrouds" over their truss assemblies to prevent this. Some kind of shroud for the Virtuoso could be made easily and would help.

On another evening, I assessed the optical quality of the telescope by viewing the planets and doing a star-test. First stop was the young Moon. The contrasty images the Virtuoso produced were so luscious I couldn't resist holding my iPhone up to the eyepiece and making a portrait of Luna.

The planets Jupiter and Saturn were attractive too but demonstrate a limit of the scope's "fast" f/5 optical system. The 10-mm eyepiece only produces 75×, not enough to show much detail on any of the planets. If you intend to do much planetary viewing with this scope, invest in a shorter-focal-length eyepiece or a Barlow lens.

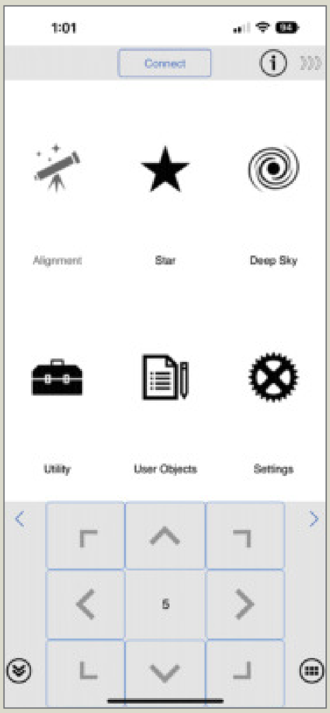
With my 4.7-mm eyepiece (160×), the planets looked good, but how was the telescope's mirror? A star-test showed the diffraction patterns looked much the same on both sides of focus — pretty good, and I wasn't surprised. Saturn was especially pleasing in the eyepiece.

Sky-Watcher's Freedom Find feature worked well after I went into the Advanced menu on the app and turned the auxiliary encoders on. These are sensors that keep track of the axis's positions while one or both clutches are released. I moved the tube manually to Saturn and then sent it on a Go To slew to the Moon. It was centered in the eyepiece when the scope stopped, showing that the encoders do their job nicely. The manual states that "enabling auxiliary encoder lowers the resolution of axis positions," so avoid activating the encoder if you don't intend to disengage the clutch.

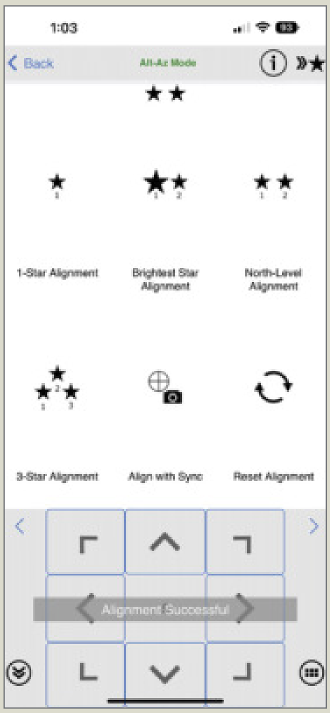
How was tracking? An alt-azimuth mount's tracking accuracy depends on the quality of the Go To alignment. Even with a casual 1-Star alignment, however, the Moon at 75× only needed occasional adjustments to recenter it.

Despite the mediocre eyepieces and stray light problem, I came to love this little telescope. The Virtuoso 150P reminded me that a good 6-inch reflector is a powerful and portable performer. So, you *can* go home again, as I did with this small reflector. The Virtuoso can provide night after night of amazing voyages through the sky and would be a difficult telescope to outgrow.

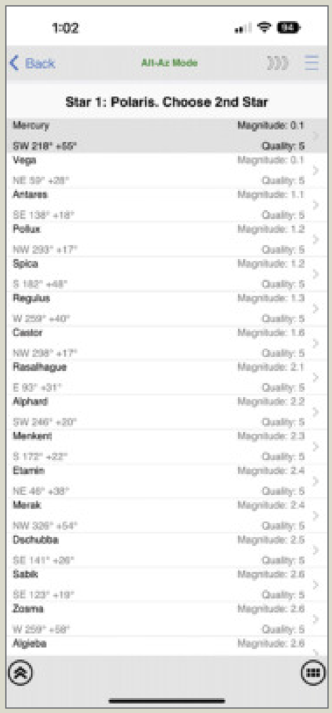
■ Contributing Editor **ROD MOLLISE** scans the night sky from his home in the outskirts of Mobile, Alabama.



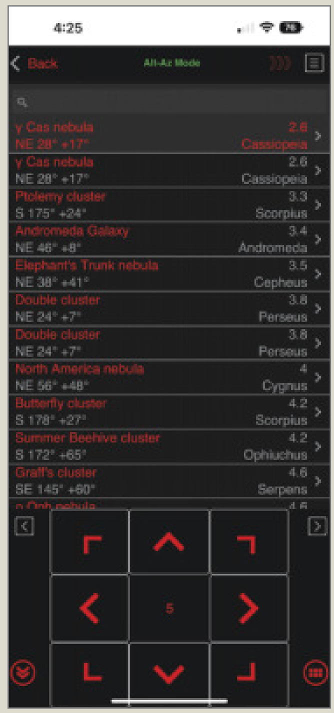
▲ The *SynScan Pro* app makes it easy to connect your smart device to the mount by touching the Connect button at the top of the opening screen. Select "SynScan 5500" and in moments your phone is paired and you're ready to move on to the alignment routines.



▲ There are four different star-alignment options to choose from in the *SynScan Pro* app, though the ones that require two or more stars produce the most accurate results.



▲ After choosing a first alignment star, the app produces an extensive list of choices for the second alignment target, which often includes the bright planets when they are visible.



▲ The *SynScan* and *SynScan Pro* apps include a night mode to help preserve your dark adaptation. This screen shows "Tonight's Best" objects.

◀ ALT-AZ GO TO

Mount manufacturer iOptron expands its line of strain-wave mounts. The HAZ31 Alt-Az Strain Wave Mount ($2,098) uses high-torque strain-wave drives in both axes to achieve precision slewing and tracking throughout the sky. The mount head weighs just 3.7 kg (8.2 lb) yet boasts a load capacity of 14 kg, without the need of cumbersome counterweights and shafts. Its multi-position saddle can be set up on the side or top of the drive base in order to accommodate binoculars. It comes with iOptron's powerful Go2Nova hand controller, which includes more than 212,000 objects in its internal database. Its black, CNC-machined casing encloses all wiring, and telescopes are secured with a dual Losmandy/Vixen-style saddle plate. Each purchase includes a soft carry case and a limited two-year warranty.

iOptron
6F Gill St., Woburn, MA 01801
781-569-0200; ioptron.com

◀ BIG DETECTOR

Camera manufacturer QHYCCD announces a new medium-format model for deep-sky imaging. The QHY461PH camera ($10,800) is designed around the extremely sensitive Sony IMX461 BSI CMOS detector, which has a 11,760 × 8,896 array of 3.76-micron-square pixels measuring 44 × 33 mm. This 102-megapixel, back-illuminated sensor provides native 16-bit A-to-D conversion on chip. Its dual-stage, thermoelectric cooling produces stable operating temperatures of as much as 35°C below ambient temperature. The camera body has a built-in dew heater around the optical window to prevent condensation. Its 77-mm aperture mates directly with the company's CFW3XL filter wheel. Each camera comes with a 2-meter USB 3 cable and CD containing the camera drivers and control software.

QHYCCD
503, Block A, Singularity Center, Shahe Town, Changping District, Beijing, China 102206
+86(10)-80709022-602; qhyccd.com

◀ APO REFRACTOR

Orion Telescopes & Binoculars adds a new model to its line of EON refractors. Orion EON 90mm ED Triplet Carbon Fiber Apo Refractor ($1,799.99) is a 3.1-inch, f/6 air-spaced apochromat that uses Hoya FC-100 extra-dispersion glass to produce excellent color correction both visually and photographically. Its carbon-fiber tube measures 45 centimeters (17.7 inches) with its dew shield retracted. The scope is equipped with a dual-speed, 2½-inch rack-and-pinion focuser that features a built-in camera angle adjuster and can hold a payload of 8.8 kg. The telescope comes with hinged tube rings, a Vixen-style dovetail mounting bar, and metal lens caps. The finderscope dovetail saddle is compatible with Synta-style quick-release finderscopes (not included).

Orion Telescopes & Binoculars
89 Hangar Way, Watsonville, CA 95076
831-763-7000; telescope.com

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.org. Not all announcements can be listed.

The Telrad Prescription

Ditch the eyeglasses while observing once and for all.

ONE OF THE MOST FRUSTRATING aspects of wearing eyeglasses while observing is that you have to take them off to look through most eyepieces, yet you have to put them back on to look through a Telrad-style finder. On-off, on-off all night until you want to throw the eyeglasses into the dark and just scan the sky at random.

If you're nearsighted, you often take your glasses off to read charts, eyepiece labels, make sketches, etc. The only time you need the glasses is when you look through the finder.

Retired optical research engineer Bob Schalck reasoned that if he could put the correction on the Telrad instead of on his face, he could eliminate the swapping on and off and enjoy observing without distraction.

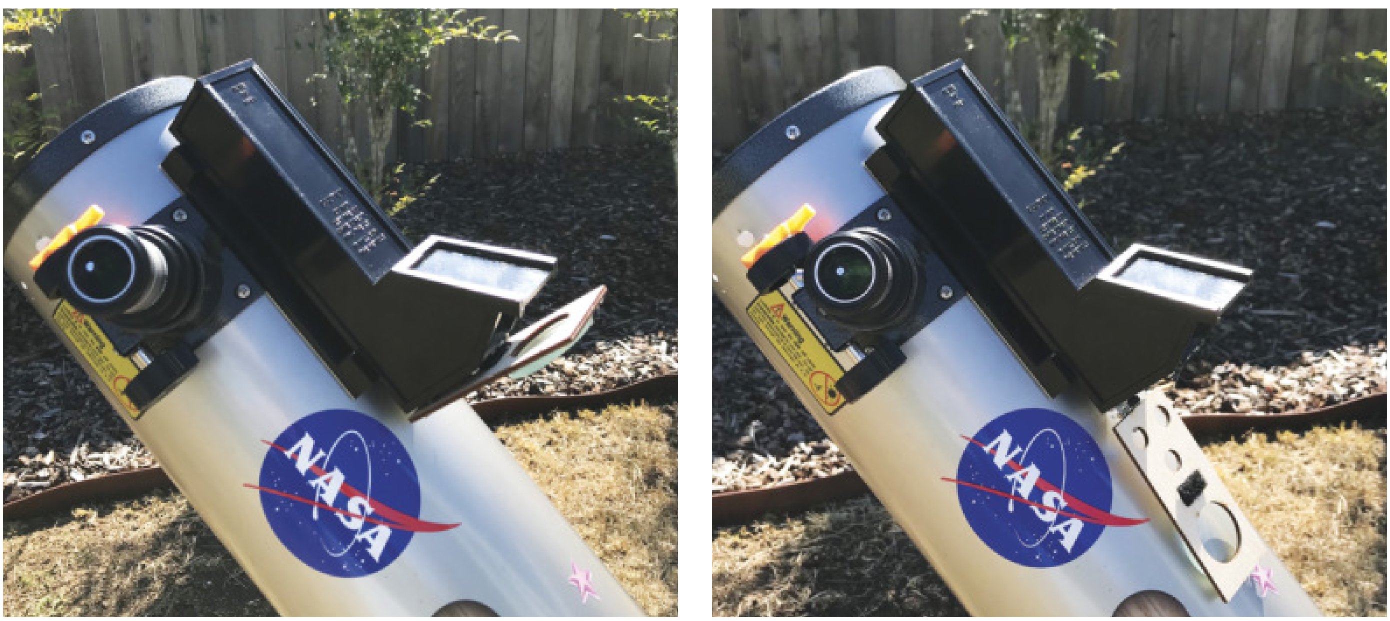
Bob is nearsighted by 3 *diopters*. Diopters are how opticians measure a lens's focal length, and it's a simple conversion to more astronomer-friendly units: Divide diopters into 1,000 millimeters (1 meter) to get the focal length in millimeters. So 3 diopters of nearsightedness require a minus-3-diopter lens to correct, so that's 1,000/–3, or –333 mm.

A little hunting on the Surplus Shed website (**surplusshed.com**) found Bob a 50-mm double-concave lens of –300-mm focal length. Close enough. In fact, the extra strength of the lens (it's –3.3 diopters) provides an advantage: At night when our pupils dilate we often become even more nearsighted, a phenomenon called *night myopia*. Having a little extra power in the corrective lens helps compensate for that.

Once Bob had his lens in hand, the next question was how to mount it on the Telrad. These finders have an angled glass window set inside an open-backed framework, so there's no convenient place to attach a lens. If you had a small enough lens, you could set it on top of the Telrad's lens (which makes the target look like it's an infinite distance away if you have 20/20 vision), but that would leave the sky blurry when you looked through the window. Bob wanted the sky to be as sharp as the target, which meant putting the lens between his eye and the glass window.

◀ The mount requires holes for the lens and for the Telrad adjustment knobs.

Also, there would undoubtedly be times when Bob still had his glasses on when he looked through the finder, so he wanted the lens to be easily removable. Ideally it should be easier to



▲ *Left:* In the upright position, the corrective lens functions like an eyeglass lens, allowing you to use a Telrad without glasses. *Right:* With the lens tilted down and out of the way, the Telrad works normally. This also gives access to the Telrad's alignment knobs.

BOB SCHALCK (3)

remove or replace than the glasses.

The solution seemed obvious: Put the lens on a hinged board that he could flip upward into place or down out of the way. Bob used 3-mm plywood and cut the lens hole with a laser, but a Forstner bit would also do the job nicely. He quickly realized that he needed additional holes to accommodate the Telrad alignment knobs, but once he drilled those, the lens mount fit snugly against the back of the Telrad. A small hinge at the bottom allows it to flip down out of the way, and a bit of Velcro holds it in place when it's flipped upward. Small magnets would work as well.

The lens Bob got was symmetrical, so it didn't matter which way he mounted it, but if you have a negative meniscus lens (innie on one side and outie on the other) you want to mount it with the concave side toward your eye, the same as your eyeglass lens. That lets the lens more closely match the curve of your eyeball and reduces distortion around the edges.

Bob hot-glued the lens in place, but other glues would do. He tried hot-gluing the hinge, too, which worked okay on the wooden piece but didn't hold to the smooth plastic finder body, so he went with screws there.

How does it work? Like a charm! The lens provides just the right amount of correction for Bob to use without his glasses. The Telrad's scale remains the same, so he can still mark his scope's aim across the sky by degrees. And he can leave his glasses in his pocket while aiming and viewing through the telescope.

Note that the more nearsighted you are, the blurrier the sky will look without your glasses. So severely nearsighted people might not find this modification useful except for final alignment after getting the scope aimed in the right general direction with their glasses on. But for people with modest corrections, this works quite well.

For more information, contact Bob at **bobschalck@gmail.com**.

■ Contributing Editor **JERRY OLTION** is thankful for contact lenses.

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Can I Build My Own Telescope?

▲ **CUSTOM FUN** One reason that's less often appreciated for making your own telescope is that you can customize it to suit your needs. The author built this optimized 6-inch, f/9 reflector (including the primary mirror) for first-rate views of the Moon and planets. The mount, however, was commercially manufactured.

ALL PHOTOS COURTESY OF THE AUTHOR

IF YOU'VE BEEN READING *Sky & Telescope* for any time at all you're probably at least dimly aware that some people like to make their own astro gear. Heck, we even have a whole department dedicated to the subject. Jerry Oltion's Astronomer's Workbench highlights the efforts of many a tinkerer. But can you — an average enthusiast with modest DIY skills — actually build a *telescope?* The answer is an emphatic "yes!" But *how* and *why* you would do so are interesting questions to ponder.

To figure out if making a scope is for you, it helps to look at what a telescope actually is. There are two main parts: the optical tube assembly (OTA) and the mount. The OTA houses the *objective*, the main light-collecting element, which is either a lens (in a refractor) or a mirror (in a reflector). And then there's the tube itself, which is often made of aluminum or even cardboard. Attached to the exterior of the tube are the focuser and the finderscope. The *mount* is the part that supports the OTA

and allows you to aim the scope at different parts of the sky. As noted in the November 2022 issue (page 72), there are a couple of different types.

Broadly speaking, there are two roads to a homebuilt scope. The first (and easiest) can be thought of as the Ikea approach: You buy the objective, finderscope, focuser, and so on, and simply assemble the instrument. In this scenario, most of your efforts will go toward the OTA since you'll likely purchase a complete mount to put it on. Scouring the Web or querying your local astronomy club is a great way to find components (and expertise).

The second approach is for the dedicated "telescope nut." Taking this route means fabricating as much as you can — including the objective. Because few amateurs construct their own refractor lenses, Newtonian reflectors are the most common DIY instruments. You can stick to a simple Dobsonian design (see the December 2022 issue, page 74) or, if you're into machining, create something very sophisticated. Really, the sky's the limit when you build your own scope from scratch.

The heart of a Newtonian reflector is its primary mirror — and crafting this component is the essence of traditional telescope making. What's involved? There are four main steps: rough grinding, fine grinding, polishing, and figuring. You begin with two disks of glass (usually of the same diameter) and grind one against the other with some abrasive between them. The ground face of the upper disk takes on a concave shape, while the lower disk develops a matching convex curve. The upper piece ultimately becomes your mirror, while the bottom one serves as a "tool." Once a curve of the desired depth is achieved, you move on to fine grinding, which uses a series of progressively finer abrasives to refine the mirror's surface. Transforming the polished face of your mirror into an exact paraboloid is the make-or-break step called "figuring." Get that right and you have a mirror. Fail and, well, you have an ashtray. (A far more detailed description of mirror grinding can be found in the July 2022 issue, page 58.)

But getting back to our initial question, even if you *can* make your own telescope, why *would* you? Not for the reason you might think. A lot of people decide to construct a scope believing that it's a great way to save money. That used to be true but no longer generally is. Not only have all the components gone up in price, but they've also become less readily available. At the same time, the cost of a complete commercial telescope has gone way down. If you want a 10-inch Dobsonian, for example, there's a good chance you can buy one for quite a bit less than you'd end up spending on all the pieces — even if you grind your own mirror.

One reason that I personally find compelling is that you can build exactly what you want. Indeed, that's what prompted me to make my 6-inch, f/9 reflector. I wanted the ultimate planetary scope but couldn't afford an expensive apochromatic refractor. So, I opted for the next best thing — a long-focus Newtonian optimized for viewing the Moon and planets. Similarly, when I found myself jetting to distant, dark-sky locations, I needed a highly portable instrument with decent aperture that I could take on a commercial flight. Here again, no commercially available scope satisfied my needs, so I built my own.

But the point of a homebuilt telescope isn't just the views it provides, rather it's the enjoyment of making it. Indeed, there are some telescope nuts who rarely look at the night sky — for them the pleasure lies in crafting a fine piece of equipment. In some respects, telescope making is a parallel hobby to amateur astronomy — but for most enthusiasts, the two intersect.

So why bother? As a confirmed telescope nut myself, I can tell you from firsthand experience that the most rewarding experience available in all of amateur astronomy is a view of the Moon, a planet, or a distant galaxy through a telescope you have fashioned with your own blood, sweat, and tears. Honestly, there's nothing like it. The satisfaction is truly priceless. ■

▲ **PLACES TO GO, THINGS TO SEE** Looking for a large telescope that he could easily transport to far-off destinations, the author (seen here in Costa Rica) built this airline-portable, truss-tube, 12¾-inch Dobsonian reflector. Most of the work went into grinding the f/4 primary mirror — the rest of the scope required only basic carpentry skills.

▲ **8-INCH TRAVELSCOPE** This short-focus Dobsonian reflector was built to conform to airline carry-on regulations. Except for the four truss poles, the entire instrument collapses down into its own base. The scope has accompanied the author to many far-flung destinations and was featured in this magazine's December 2001 issue, page 120.

▷ RAISING THE BAR

Dan Crowson

NGC 1365 is a large, double-barred spiral galaxy in the southern constellation of Fornax. Dark dust lanes accentuate the galaxy's central bar, while reddish star-forming regions line its spiral arms.

DETAILS: *AstroSysteme Austria AZ1000 Ritchey-Chrétien telescope and FLI PL16803 camera. Total exposure: 4.25 hours through LRGB filters.*

▽ A YEAR ABOVE TEHRAN

Parisa Bajelan

This composite of 51 photographs captured above the high-rise buildings in Tehran, Iran, reveals the Sun's year-long, figure-8 pattern. The photographer took each image roughly one week apart at 7:40 a.m. local time from March 2021 to March 2022.

DETAILS: *Canon 6D camera and Canon EF 16-to-35-mm wide-angle lens. Composite image consisting of a single 1/30 second exposure at f/4.5 for the foreground, while the solar images are each 1/400 second at f/22 through a neutral-density filter.*

OPHIUCHUS AND THE SCORPION

Jorge Restrepo

The Rho Ophiuchi cloud complex (left) on the border of Ophiuchus and Scorpius is a conglomeration of dark, emission, and reflection nebulae. The red supergiant Antares illuminates the yellowish dust to the left of globular cluster M4. To the top right is the sprawling, faint reflection nebula IC 4592, known to some as the Blue Horsehead Nebula.

DETAILS: *ZWO ASI2600MC Pro camera and Rokinon 135-mm lens. Total exposure: 12 hours.*

DUSTY BULL

Kurt Zeppetello

LBN 777 is a brighter patch of the enormous Taurus molecular cloud that permeates this region. The nebula's dust reflects light from the surrounding stars, causing LBN 777's brownish glow. South is up.

DETAILS: *Astro-Tech AT115EDT refractor and ZWO ASI1600MM Pro camera. Total exposure: 23.32 hours through LRGB filters.*


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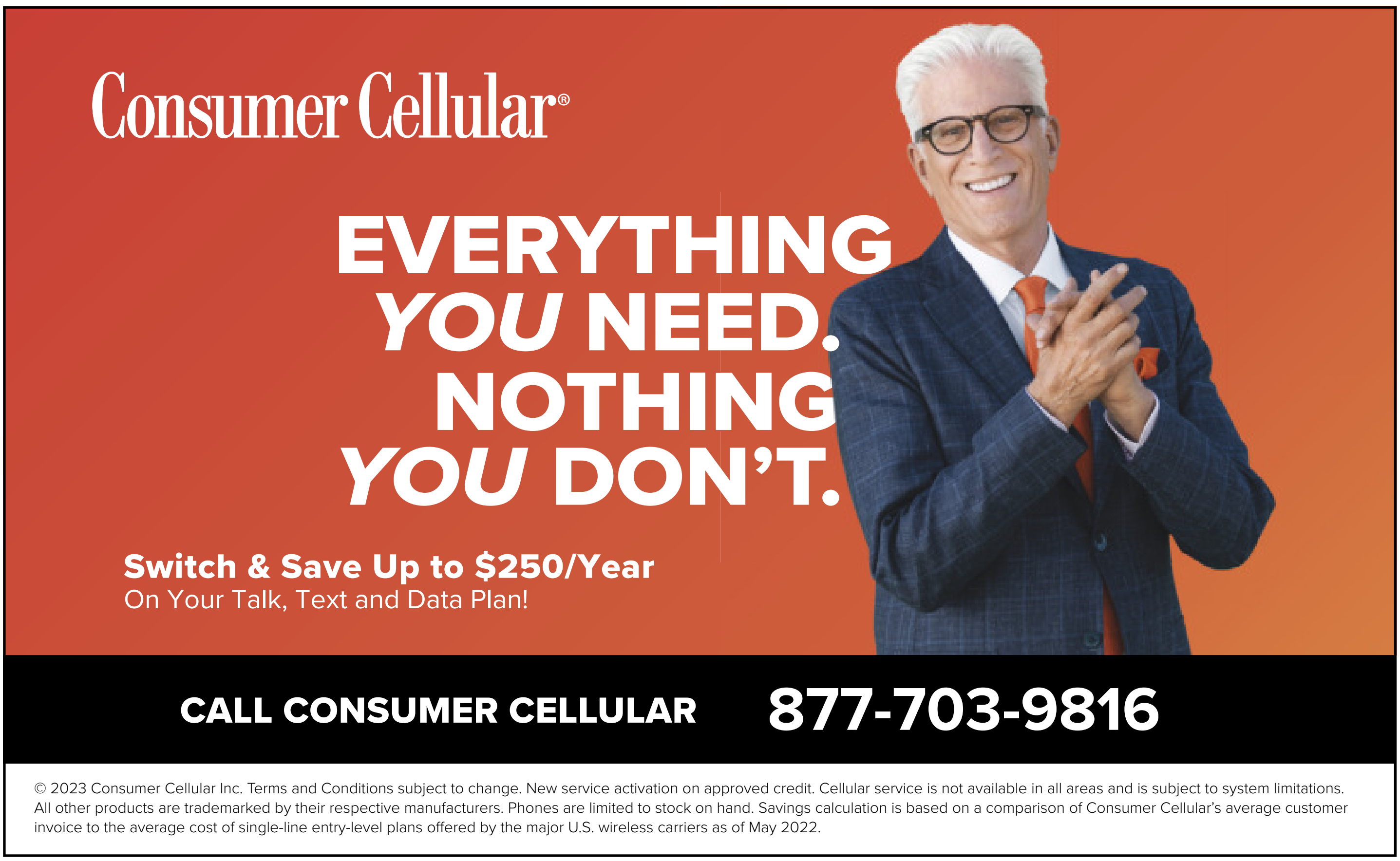
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▷ ANOTHER BARRED SPIRAL

Ian Gorenstein

Barred spiral galaxy M109 in Ursa Major is one of the most distant objects in Charles Messier's catalog. The galaxy's spiral arms are streaked with bright stellar nurseries.

DETAILS: *Celestron EdgeHD 14-inch Schmidt-Cassegrain and QHY268M CMOS camera. Total exposure: 7.5 hours through LRGB filters.*

▽ OVER THE PAINTED WALL

Vince Farnsworth

The Milky Way from Sagittarius (left) to Perseus (right) arches above Gunnison National Park's Painted Wall, the highest cliff in Colorado, in early September 2022.

DETAILS: *Canon EOS Rα camera and Canon 15-to-35-mm lens. Mosaic of several exposures, each 150 seconds at f/3.5, ISO 1600 for the sky and ½ second at f/11, ISO 400 for the foreground.*

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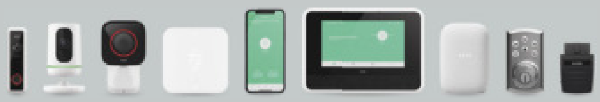

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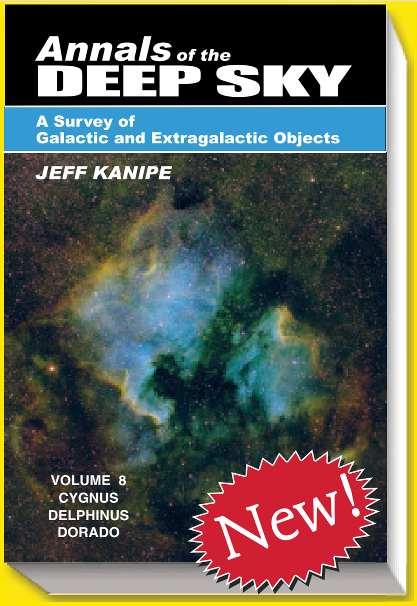

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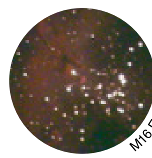
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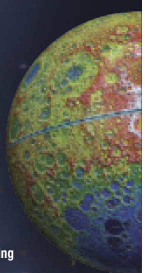

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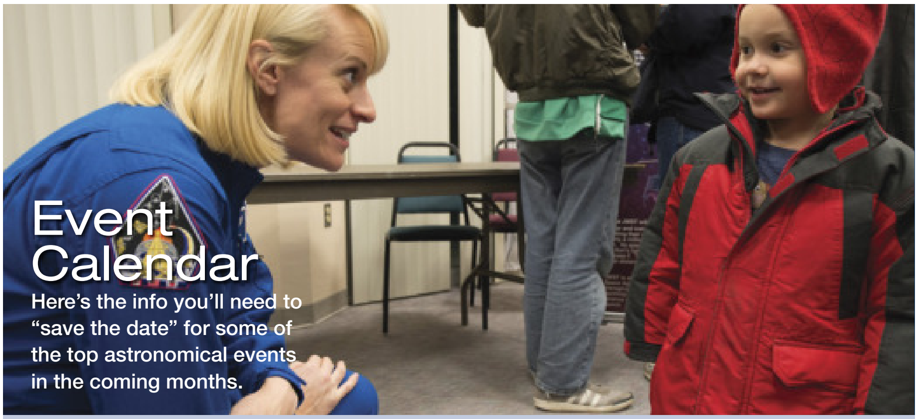

NASA / BILL INGALLS

Event Calendar

Here's the info you'll need to "save the date" for some of the top astronomical events in the coming months.

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GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCStarParty

June 14–17
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
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June 14–18
GOLDEN STATE STAR PARTY
Adin, CA
goldenstatestarparty.org

June 14–18
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 14–18
YORK COUNTY STAR PARTY
Susquehannock State Park, PA
http://yorkcountystarparty.org

June 15–18
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 15–18
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
https://is.gd/WIObserversWeekend

July 16–22
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

July 18–23
OREGON STAR PARTY
Ochoco National Forest, OR
oregonstarparty.org

July 26–29
ALCON 2022
Baton Rouge, LA
alcon2023.org

August 8–12
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

August 12–20
MT. KOBAU STAR PARTY
Osoyoos, BC
mksp.ca

August 14–20
MAINE ASTRONOMY RETREAT
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An Observatory for Seniors

The author's brainstorm brought deep satisfaction to his retirement community — and to himself.

THERE WAS A PROBLEM . . . a *big* one. At 68 I retired from a busy private practice in clinical psychology. I enjoyed my work, and it was with mixed emotions that after more than 34 years I decided to leave to focus on other interests.

In April 2018 my 80th birthday rolled around. That landmark event prompted my wife and me to begin serious discussions about where we wanted to live in our final years. We decided the best path for us was to move into Westminster Village (WV), a continuing-care retirement community in Scottsdale, Arizona, near our home.

And the problem? I'd been using our backyard for imaging with my new 11-inch Celestron EdgeHD scope. Moving to WV presented me with the serious issue of where to use my telescope. The staff made clear there was no place to leave my instrument set up overnight. At my age, setting up and taking down a scope of this size whenever I wished to image is a definite deterrent to enjoying my hobby.

But then I had an idea that changed the entire landscape for me . . . and for everyone at WV. How about creating an observatory where my telescope could be permanently mounted and used for the benefit not only of myself but of the residents, employees, and their families?

In March 2019 I presented my idea to the complex's CEO. Happily, he thought it was a grand idea. With his blessing and that of the entire staff, I began to work out the details of constructing and operating an observatory to house my scope and all its ancillary gear.

As with any intricate project, unforeseen difficulties arose. COVID and supply-chain problems delayed things, and assembling the Technical Innovations 10-foot-diameter Home-Dome observatory took longer than anticipated. But in early 2022 our crew completed the dome and installed the scope.

A key part of the observatory is the "observing room" located in a lounge area inside the main building near the dome. Through a home network, we use a program that allows me to display real-time images from the scope's video camera on four large-screen TVs hung on walls around the room. In this way, all residents, regardless of mobility restrictions, can savor astronomical sights while seated in a climate-controlled environment. We display images both from my telescope and downloaded from professional observatories such as the James Webb Space Telescope.

To help me operate the observatory, I recruited six residents to become "assistants." They completed a seven-week observational astronomy course I taught. As time goes on, we continue to improve the operation. Recently we mounted an 80-mm solar scope on the main telescope and can now observe sunspots and prominences.

The observatory has had a very positive impact. Many residents, I learned, had never looked through a telescope. Their excitement and gratitude for being able to do so now is tangible. Sharing my knowledge accumulated over decades with others in my age group has been deeply meaningful. I hope my experience inspires other amateurs in retirement communities to do the same.

■ Now 85, **DR. ROBERT RICHARD** is a lifelong amateur astronomer.

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